SCIENTIFIC AGRICULTURE

VOLUME 27 NOVEMBER, 1947 No. 11

EFFECT OF VARIOUS SOIL SUPPLEMENTS ON THE VIRULENCE AND PERSISTENCE OF *RHIZOCTONIA SOLANI*[1]

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[Received for publication June 18, 1947]

In a previous study (5), it was found that the virulence of *Rhizoctonia Solani* Kühn was usually greater in natural, artificially infested, Edmonton black loam than in the same soil steam sterilized, and that (4), in general, the pathogen tended to be more virulent in an infertile podsol soil than in the fertile black loam. These results suggested that certain soil amendments might directly or indirectly affect the virulence and persistence of this pathogen in field practice. This paper presents data obtained from six of eight separate experiments on the possibility just mentioned.

MATERIALS AND METHODS

Data were obtained during one or more years on the effect of the following amendments or treatments: sulphur, cornmeal, sucrose, dextrose; the nitrates of calcium, sodium and potassium; the sulphates of magnesium, ammonia, aluminium, and potassium; the phosphates of ammonia and sodium; the hydroxides of potassium, calcium, and sodium; iron tartrate; borax; sodium chloride; urea; and natural and steam sterilized soil. No attempt was made to have the rates of application of the various chemicals comparable, or even the same from year to year. The rate of a treatment was often much heavier than would be economically feasible. Comparative tests were also made of the effects of the different rates of most of the amendments mentioned, on the normal growth of the host where the pathogen was absent.

The various experiments were prepared during April of each year and replanted at 21-day intervals thereafter, five, six, seven, or eight times, depending on conditions. The soil used throughout was fresh, unsterilized, Edmonton black virgin loam, obtained from the same location. Wyatt and Newton (8) have described and supplied the following comparative data for this type of soil: nitrogen, 0.53%, phosphorus, 0.10%, calcium, 0.94%; magnesium, 0.50%; pH 6.4.

The virulence and also the persistence of the pathogen in the soil were indicated by a disease rating made on potato sprouts from sets of the Early Ohio variety. These sets, each weighing 10 gm. and of uniform shape, were cut from clean semi-dormant tubers stored at 2° C. The

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freshly cut sets were immersed for eight minutes in a 1 : 1,000 solution of mercuric chloride to which was added 1% by volume of hydrochloric acid, then rinsed in tap water and planted.

Inoculum, consisting of a virulent culture of *R. Solani* (Culture No. 76), increased in steam-sterilized, black loam, was employed to infest artificially the experimental soil. The rate was one part of soil inoculum to 15 parts of soil. Uniform infestation of the soil was insured by thoroughly mixing and sifting the required quantity of soil for all series (excepting the steam sterilized one) and inoculum in a common pile. Each amendment was then added to the required weight of this uniformly infested soil. With the exception of cornmeal, lime, and sulphur, each chemical was dissolved in the quantity of water necessary to bring the soil's water content to about 30% of its moisture-holding capacity. Each lot of treated soil was then put into the requisite number of containers for a given series and let stand for ten days at 16°-17° C. before planting.

At the end of each 21-day period, the soil and sprouts in the various containers were removed. The sprouts were rated for disease, and the degree of massing of mycelium and formation of sclerotia on them recorded. All containers were then replanted immediately. In the case of Experiments 1 and 2 (flasks), and 4 and 5 (crocks), the soil, emptied at each replanting from the various containers of a given treatment, was thoroughly mixed in one pile before being used again. However, in Experiments 3 (flasks), 6, 7 and 8 (crocks), care was taken not to mix any of the soil from one container with that from another. In this way a more accurate record of the varying biological behaviour of each replicate during the season was possible than when the soil was mixed at each replanting.

Owing to the high relative humidity of the incubation room, the use of cotton plugs in the flasks, and a paper mulch in the case of crocks, only a very small quantity of water was necessary at the end of the third or fourth planting to restore the soil's original water content.

The pH values of the treated units were determined colorimetrically at the end of the first and fourth plantings.

Disease severity was expressed numerically. Sprouts having lateral lesions, but the tips still intact, were assigned values below 6, according to severity. Within this class comparative ratings could be made fairly accurately, but this was no longer possible when the tip of the primary sprout was killed at a point one inch or more from the set, and sound secondary ones had developed from the unaffected nodes or base. Therefore, values ranging from 6 to 7, inclusive, were assigned to severely diseased sprouts. In this latter class the majority of them rated 6 or 6.5. Only in a relatively few instances was the rating 7 given. It will be obvious, then, that a disease rating of 6 is very severe, and one of 7 equivalent to practically 100%. The ratings as listed are comparable throughout and were all made by the same person. (These are illustrated in Figure 1.)

During 1938 and 1939, the effects of several rates of the various soil supplements on disease development and growth of the potato sprouts were tested in Experiments 4 and 5. With the aid of this information, the rates used in Experiments 6, 7, and 8 were selected. The data for Experiments 4 and 5 are not included in this report.

FIGURE 1. Lesioned potato sprouts, 21 days old, illustrating severity of different disease ratings. Left to right—1, 2, 3, 4, 5.5 and 6.5.

In all the experiments, the temperature was 16°-17° C., and the soil water content approximately 30 per cent of its water holding capacity. The six experiments reported were carried out from 1937 to 1942, inclusive. There were five successive 21-day plantings in Experiments 2 and 3, six in Experiments 6 and 8, seven in Experiment 1, and eight in Experiment 8. In Experiment 1, there were two extra 21-day plantings during April and May of the following season and one extra planting during April in Experiment 3.

TABLE 1.—EFFECT OF VARIOUS SOIL TREATMENTS ON VIRULENCE AND PERSISTENCE OF *Rhizoctonia Solani* AS INDICATED ON POTATO STEMS (EXPERIMENTS 1, 2 AND 3)

Treatment	Rate*	Average disease rating per planting								
		1	2	3	4	5	6	7	April†	May†
		%	%	%	%	%	%	%	%	%
Experiment 1										
Sodium nitrate	0.53	39	20	37	10	0	3	Trace	0	0
	0.80	9	2	21	0	0	0	0	Trace	0
	1.07	0	0	14	1	0	Trace	0	0	0
Cornmeal	3.00	14	36	2	46	60	42	13	3	0
	7.00	0	32	48	60	42	15	4	0	0
	10.00	0	7	25	30	1	3	0	Trace	0
Sucrose	0.57	42	34	33	23	65	56	34	19	1
	1.15	54	47	58	55	67	50	60	42	40
	1.97	0	65	60	70	56	63	34	18	27
	2.95	1	57	53	30	5	5	0	Trace	0
Control (continuous)	—	50	58	54	27	61	48	48	4	1
Control (fresh)	—	—	60	58	48	37	56	51	52	38
Control (non infested)	—	0	0	0	0	0	0	0	0	0
Experiment 2										
Sodium nitrate	0.51	19	2	43	0	0	—	—	—	—
	0.76	8	0	0	0	1	—	—	—	—
	1.02	1	0	0	0	0	—	—	—	—
Cornmeal	3.00	24	47	36	10	8	—	—	—	—
	7.00	0	0	15	2	Trace	—	—	—	—
	10.00	0	3	26	0	0	—	—	—	—
Calcium nitrate	0.21	50	58	57	43	35	—	—	—	—
	0.33	35	0	2	0	2	—	—	—	—
	0.41	32	1	0	1	0	—	—	—	—
Dextrose	0.55	65	35	3	25	41	—	—	—	—
	1.11	0	12	0	0	0	—	—	—	—
	1.88	0	0	0	0	0	—	—	—	—
Steamed soil	—	30	10	26	10	6	—	—	—	—
Control (continuous)	—	55	42	44	14	16	—	—	—	—
Control (fresh)	—	—	66	59	39	40	—	—	—	—
Control (non-infested)	—	0	0	0	0	0	—	—	—	—
Experiment 3										
Sodium nitrate	0.51	26	6	0	0	0	—	—	0	—
	0.76	4	3	1	0	17	—	—	0	—
Cornmeal	3.00	4	23	31	4	10	—	—	2	—
	7.00	0	15	31	6	0	—	—	0	—
Calcium nitrate	0.21	58	30	26	24	10	—	—	2	—
	0.33	41	35	30	30	18	—	—	10	—
Dextrose	0.55	24	31	49	30	46	—	—	46	—
	1.11	50	21	23	15	4	—	—	0	—
Urea	0.09	54	23	9	11	2	—	—	1	—

* Grams of treatment per 100 grams of soil at 30% moisture-holding capacity.
† Following season.

TABLE 1.—EFFECT OF VARIOUS SOIL TREATMENTS ON VIRULENCE AND PERSISTENCE OF *Rhizoctonia Solani* AS INDICATED ON POTATO STEMS (EXPERIMENTS 1, 2, AND 3)—*Con.*

Treatment	Rate*	Average disease rating per planting								
		1	2	3	4	5	6	7	April†	May†
		%	%	%	%	%	%	%	%	%
Experiment 3—Con.										
Steamed soil	—	8	11	45	53	45	—	—	31	—
Control (continuous)	—	50	43	38	22	18	—	—	18	—
Control (fresh)	—	—	54	53	67	52	—	—	34	—
Control (non-infested)	—	0	0	0	0	0	—	—	0	—

* Grams of treatment per 100 grams of soil at 30% moisture-holding capacity.
† Following season.

RESULTS

Experiments 1, 2 and 3

Disease Ratings

There was a rather uniform tendency for the disease rating to be reduced by *sodium nitrate* in all three experiments, and the effect was proportionate with the rate of application, beginning with the first planting.

The depressing effect on disease of *cornmeal* was variable and probably intermediate between that of sodium nitrate and calcium nitrate in all three experiments. There was a tendency for the complete suppression of disease in the first plantings.

Calcium nitrate depressed disease development less than did sodium nitrate or cornmeal. This was particularly evident in the first planting.

The effect of *dextrose* on the disease rating in the second and third experiments seemed to follow the same general pattern produced by calcium nitrate, although perhaps with more variability.

The rather light application of *urea* in Experiment 3 appeared to produce in each successive planting a fairly sharp decline in the disease rating, as compared with dextrose and calcium nitrate. However, no general conclusion can be drawn without further tests.

In the first experiment, the disease was greatly depressed in *steamed soil* in the first and second plantings, but in the third, fourth, and fifth plantings it was considerably greater than in corresponding plantings of the untreated control soil. However, in the second experiment, the trend was downward, beginning with the first planting, and the disease incidence was always below that which occurred in the control soil series.

Sucrose was outstanding in that it appeared to favour the virulence of the pathogen in practically all the plantings of the first experiment.

Persistence of Pathogen in Soil

The pathogen persisted longer in certain treatments than in others during a period of about one year. In all cases where the disease rating was low or negligible in the last planting in the autumn of the first season, there was only a trace of disease or none the following spring. Conversely,

TABLE 2.—EFFECT OF VARIOUS TREATMENTS ON VIRULENCE AND PERSISTENCE OF *Rhizoctonia Solani* IN EDMONTON BLACK LOAM, AS INDICATED ON POTATO SPROUTS (EXPERIMENTS 6, 7 AND 8)

Treatment	Experiment	Estimated acre rate	Rate*	Average disease rating per planting								pH†
				1	2	3	4	5	6	7	Av.	
	No.	cwt		%	%	%	%	%	%	%	%	
Sodium nitrate	6	86	0.43	29	16	3	9	12	7	—	12.6	6.2
	7	86	0.43	23	6	5	14	24	22	17	15.8	—
	8	86	0.43	26	0	0	0	0	0	—	4.3	—
Potassium nitrate	6	142	0.71	18	4	3	5	21	16	—	11.2	—
	7	86	0.43	26	8	13	24	26	16	31	20.6	6.2
	8	86	0.43	24	0	0	0	0	0	—	4.0	—
Calcium nitrate	6	132	0.66	37	33	9	30	43	42	—	32.3	6.0
	7	132	0.66	26	9	7	20	19	33	21	19.3	6.0
	8	132	0.66	24	4	0	0	0	0	—	4.6	—
Ammonium sulphate	7	76	0.38	58	22	13	32	3	13	21	23.1	5.2
	8	76	0.38	8	1	0	0	0	0	—	1.5	—
Ammonium phosphate	6	94	0.47	60	53	25	19	0	1	—	26.3	—
	7	76	0.38	58	21	4	18	3	21	18	20.4	5.8
	8	76	0.38	4	0	0	0	0	0	—	0.6	—
Sodium phosphate	7	114	0.57	51	32	26	5	7	5	—	21.0	6.4
Triple superphosphate	8	38	0.19	40	60	37	0	1	0	—	23.0	6.2
Potassium sulphate	7	76	0.38	43	16	11	47	29	35	39	31.4	5.6
	8	76	0.38	12	24	2	0	0	0	—	6.3	—
Magnesium sulphate	6	28	0.14	61	63	52	38	49	49	—	52.0	—
	8	28	0.14	33	32	18	0	0	0	—	1.4	6.1
Sodium hydroxide	6	42	0.21	44	35	37	21	22	22	—	28.5	—
	7	74	0.37	16	2	1	5	12	12	0	6.9	7.3
	8	74	0.37	40	38	25	2	0	2	—	17.8	—
Potassium hydroxide	6	74	0.37	60	69	54	29	31	17	—	43.3	—
	7	74	0.37	29	13	1	21	39	37	37	25.3	7.3
	8	74	0.37	46	39	0	0	0	0	—	14.2	—
Calcium hydrate	6	28	0.14	60	63	45	46	42	38	—	49.0	—
	7	28	0.14	51	28	39	40	48	55	60	45.9	6.2
	8	28	0.14	29	60	28	0	3	1	—	20.2	—
Sulphur	6	28	0.14	63	22	41	34	40	28	—	38.0	—
	7	28	0.14	56	57	40	50	43	24	16	40.9	5.8
	8	28	0.14	22	21	2	0	0	0	—	7.5	—
Iron tartrate	6	28	0.14	57	62	56	53	59	46	—	55.5	6.2
	8	28	0.14	44	19	0	0	0	0	—	10.5	—
Dextrose	6	270	1.35	62	16	41	30	43	35	—	37.8	—
	7	218	1.09	6	1	Trace	32	35	26	34	19.2	6.1
	8	218	1.09	48	12	1	0	3	6	—	11.7	—
Sucrose	6	214	1.07	23	29	23	8	18	17	—	19.7	—
	7	278	1.09	30	48	26	40	31	56	29	37.1	6.[illegible]
	8	278	1.09	21	60	60	40	20	Trace	—	33.5	—

* Grams of treatment per 100 grams of soil at 30% moisture-holding capacity.
† After 4th planting.

TABLE 2.—EFFECT OF VARIOUS TREATMENTS ON VIRULENCE AND PERSISTENCE OF *Rhizoctonia Solani* IN EDMONTON BLACK LOAM, AS INDICATED ON POTATO SPROUTS (EXPERIMENTS 6, 7 AND 8)—*Continued*

Treatment	Experiment	Estimated acre rate	Rate*	Average disease rating per planting								pH†
				1	2	3	4	5	6	7	Av.	
	No.	cwt.		%	%	%	%	%	%	%	%	
Cornmeal	6	1200	6.00	0	27	12	1	3	2	—	7.5	6.1
Sodium chloride	8	74	0.37	19	17	36	15	0	0	—	12.4	6.0
Steam sterilized soil	7	—	—	12	9	27	59	57	56	54	39.1	6.1
	8	—	—	0	44	1	5	0	0	—	8.3	—
Controls (non-infested)	6, 7, 8	—	—	0	0	0	0	0	0	0	—	6.2
Controls (continuous)	6	—	—	60	59	60	58	48	13	—	49.6	—
	7	—	—	40	49	35	55	55	56	40	47.1	—
	8	—	—	27	60	59	29	0	1	—	29.3	—
Control (fresh)	7	—	—	45	48	35	23	44	60	59	44.8	—

* Grams of treatment per 100 grams of soil at 30% moisture-holding capacity.
† After 4th planting.

severe disease developed only in those soil series having a high disease incidence in the last fall planting. However, it is of interest to note that in five out of twelve series having high incidence in the last planting at the end of the first season, relatively little or no disease developed on the first planting following winter storage of the originally infested soil.

Sodium nitrate and cornmeal were distinctly unfavourable to the pathogen's persistence in all experiments. Sucrose was definitely favourable in the first experiment. There was a tendency for both calcium nitrate and dextrose to favour persistence in the third experiment, but not in the second.

Experiment 6

The average disease rating of the six plantings of the continuous soil control was 45.7%. Low ratings of 7.5, 11.2, and 12.6% were obtained in the cornmeal, potassium nitrate, and sodium nitrate series, respectively, and high ratings of 55.5, 52.0, and 49.0%, respectively, in the iron tartrate, magnesium sulphate, and calcium hydrate treatments. Lower disease ratings of 43.3, 38.0, and 37.8% developed in the potassium hydroxide, sulphur, and dextrose series, respectively; and 32.3, 28.5, and 26.3% in the calcium nitrate, sodium hydroxide, and ammonium phosphate series, respectively. The rating for the sucrose series was 19.7%, or about one-half that obtained in the dextrose series.

Experiment 7

In this experiment, carried out during 1941, the average disease rating for the seven successive plantings in the same soil of the continuous soil control series was 47.1%, or slightly more than for the corresponding soil

control of Experiment 6 in 1940. The lowest average disease rating, 6.9%, was in the sodium hydroxide series. In the sodium nitrate series, the rating was 15.8%. The average disease ratings for dextrose, calcium nitrate, sodium phosphate, ammonium phosphate, and potassium nitrate were all approximately 20%, while those for ammonium sulphate and potassium hydroxide were slightly higher, namely, 23.1 and 25.3%, respectively, and for the potassium sulphate series, 31.4%. The highest average ratings were in the sucrose, steamed soil and sulphur series, being approximately the same, namely, 37.1, 39.1, and 40.9%, respectively. The highest rating of all was for calcium hydrate, being 45.9%, as compared to 47.1% for the continuous soil control. Cornmeal, magnesium sulphate, and iron tartrate were not tested.

Table 3.—Data from Experiment 7 illustrating the variability in disease rating among replicates of various soil amendments

Treatment	Replicate	Average disease rating per planting								
		1	*	2	3	4	5	6	7	8†
	No.	%	%	%	%	%	%	%	%	%
Sodium nitrate	1	4	*20*	0	Trace	Trace	13	3	1	**53**
	2	36	*0*	8	5	0	3	Trace	0	**58**
	3	29	*0*	11	8	41	50	59	51	60
Potassium nitrate	1	43	*10*	Trace	0	0	1	0	0	**60**
	2	26	*10*	20	39	60	50	31	38	59
	3	9	*30*	4	0	11	29	28	58	52
Calcium nitrate	1	25	*0*	4	7	8	Trace	9	2	**53**
	2	4	*62*	2	11	0	7	38	60	52
	3	48	*0*	20	2	51	50	50	60	60
Calcium hydrate	1	38	*0*	0	45	60	29	60	60	47
	2	61	*0*	23	49	41	58	50	60	4
	3	55	*0*	61	26	34	58	54	60	53
Sulphur	1	60	*0*	56	60	52	37	22	27	11
	2	51	*0*	60	49	65	37	46	1	**59**
	3	57	*0*	55	12	4	54	4	21	2
Dextrose	1	1	*90*	1	Trace	48	60	33	46	27
	2	9	*20*	Trace	Trace	46	37	46	14	1
	3	9	*30*	0	Trace	Trace	7	0	41	52
Sucrose	1	45	*0*	43	14	57	54	53	60	60
	2	46	*10*	48	62	65	38	60	28	60
	3	1	*66*	55	Trace	0	0	54	0	**31**
Control (continuous)	1	36	*20*	35	52	58	60	60	0	**53**
	2	41	*10*	60	68	60	40	60	60	44
	3	52	*0*	52	0	60	60	53	60	35
	4	12	*20*	38	0	50	60	60	60	49
	5	45	*0*	20	7	60	60	60	24	30
	6	15	*30*	7	19	43	49	39	36	10
Control (fresh)	1	—	—	16	30	0	24	60	58	32
	2	—	—	25	37	10	60	60	60	21
	3	—	—	14	41	60	44	60	60	15

* Figures in italics are for per cent plants clean.
† Figures in heavy black type are for re-infested replicates.

Experiment 8

The results of this experiment are of unusual interest, owing to the abrupt and more or less general disappearance of disease in many of the treatments, despite a fairly high disease rating in the first plantings. In the nitrogenous treatments there was either no disease or practically none after the first planting, whereas in all but one of the units treated with the non-nitrogenous amendments, disease disappearance was postponed until the third, fourth, or fifth planting. Without critical data regarding the actual microbial population of these soils, the possible connection between the nitrogenous amendments and early disease disappearance cannot be explained. On the other hand, the tendency has been indicated more or less consistently in all eight experiments of this study. It is emphasized that a fairly high disease content was maintained in the continuous soil control until the fifth planting, and until the sixth in the units treated with sucrose. The favourable effect of sucrose, and also of untreated soil, upon the pathogen's persistence has been evident throughout these studies.

Variability in Disease Rating Among Replicates

Despite uniform initial infestation of the soil, the amount of disease in the replicates of the various treatments often fluctuated very widely. This occurred in the same replicate from one planting to the next (Figure 2), as well as in the three replicates of the same planting of a given treatment. Selected data are arranged in Table 3 to illustrate this variability. Obviously it was much more general and pronounced in the soils treated with sodium nitrate, potassium nitrate, calcium nitrate, or dextrose, than in those treated with sucrose, sulphur, or hydrated lime, or in the untreated soil control. In certain replicates, disease was greatly depressed in the first planting, and thereafter there was little or none, or a gradual or marked increase of it. In other cases the disease was severe in the first planting, but subsequently only a trace or none, or it might continue severe. Usually when the disease was severe, all the stems, or a high percentage of them, were attacked (Table 3). It is significant that a percentage of the susceptible host plants, or all of them, may escape attack in a soil thoroughly infested with a potentially virulent pathogen. The reason for the variability indicated or for the apparent disappearance of the pathogen from the soil of certain replicates sooner than from others is not clear from these data. When such replicates were re-infested at the end of the seventh planting severe disease developed in the eighth planting, indicating that the pathogen could be re-established, at least temporarily. No tests were made to determine whether the pathogen would again tend to disappear sooner in these replicates than in those where the disease had been uniformly severe throughout.

DISCUSSION

The disease data listed in Tables 1, 2, and 3 were obtained from six experiments involving about 14,000 21-day-old potato plants. They were grown in artificially infested, natural, virgin, black Edmonton loam, to which were added various supplements. The object of this study was to observe, in successive plantings, the differential effect of the various treatments on the virulence and persistence of *R. Solani* in natural soil over a period of time.

Apparently some of the treatments tended more than others to reduce the disease, and also to favour variability of disease incidence from planting to planting in the same replicate, and to shorten the pathogen's persistence in the soil.

In comparing the results from the various organic and non-organic amendments, it should be noted that in the natural soil without any supplement (continuous control), the pathogen's virulence and persistence were maintained at about as uniformly high a level throughout all experiments as in any of the treatments, being rivalled only by sucrose.

Sucrose consistently favoured both virulence and persistence, whereas the results from the same rate of dextrose were quite variable (Table 3). Calcium hydrate, magnesium sulphate, and even sulphur, each at 28 cwt. per acre, were also very favourable. Cornmeal was definitely unfavourable, and nearly always completely suppressed disease in the first planting.

As a group, the nitrogen salts obviously tended to suppress the disease more than the non-nitrogenous salts, and they were also detrimental to the pathogen's persistence. Sodium nitrate was moıe effective in this respect than the others. A longer test period would probably accentuate the effects of the various treatments on the pathogen's persistence.

The data in Table 3 deserve close examination, because they indicate more accurately the variations in the disease produced by the pathogen under the influence of the various soil treatments, than can be gained from the averaged results as listed in Tables 1 and 2. The incidence of the disease in the various replicates of the first planting is fairly high and uniform. The variability of each replicate through the eight successive plantings is, in general, more prevalent in the soils treated with the nitrogenous salts than in the case of the non-nitrogenous supplements. In the natural, untreated soil, the degree of stability of virulence of the pathogen is outstanding, and it is quite persistent. The lime replicates have a marked tendency in this direction also. There is a distinct contrast in variability of disease incidence between the sucrose and dextrose series. Although in a number of cases there was only a trace or no disease in the seventh planting, maximum disease developed during the next 21 days in the eighth planting in the re-infested soil. Briefly, these data show that, regardless of the continuous presence of a susceptible host in the soil, available food, and a uniformly favourable soil temperature and water content, *R. Solani* may soon practically disappear from the soil, or persist for a relatively long time. The data also show that the pathogen may remain in the soil and still produce no disease.

The basis for these interesting effects has not yet been determined. There was no obvious correlation between differences in soil reaction and disease severity or persistence of the pathogen in this study. That the temperature and water content of the soil were favourable to disease expression is indicated by the results from the continuous controls of all experiments. Blair (1) observed that excess respiratory carbon dioxide content, arising from profuse growth of the associated fungi in the soil, depressed the growth of *R. Solani*. This might apply to some extent in the case of cornmeal, where the associated fungal growth was profuse, but it would not in the case of the nitrogenous supplements, where such growth

FIGURE 2. Illustrating extreme variability in disease development in two replicates in the same planting (potassium nitrate series, 5th planting, Table 3). Left—one of the ten sprouts slightly attacked; Right—all sprouts severely attacked

is characteristically light. Also, it would not explain the sudden and wide temporary fluctuation in disease incidence in different plantings of the same replicates that occurred in all treatments, and in some more than in others. Moreover, as already pointed out (5), and frequently observed during this study, profuse mycelial growth of the pathogen may hinder rather than favour infection of the host. Possibly the type of hyphal growth and its physiology as modified by the environment and/or the associated soil microflora, are determining factors. Certainly numerous fresh hyphal "budding" would seem important to successful infection. In

this connection it may be added that in another study, to be reported later, the pathogen grew uniformly well in an untreated soil, and put out many small hyphal branches. By comparison, it grew poorly in the same soil treated with sodium nitrate, and was greatly depressed and often apparently eliminated by a cornmeal supplement. Weindling (7) showed that *Trichoderma lignorum* produced a diffusible substance that on artificial media was toxic and destructive to the hyphal cells of *R. Solani.* However, Daines (3) found that this toxic principle was destroyed in a soil of pH 5.6. According to Cordon and Haenseler (2), *Bacillus simplex* yielded a toxic substance that completely suppressed growth of the pathogen on artificial media. The author (6) obtained from the soil a bacterial isolate which partially suppressed the pathogen's growth in a sterilized soil.

Therefore, it seems logical to conclude from the extensive circumstantial evidence presented in Tables 1, 2, and 3, that most instances of apparent decline of the pathogen in the soil, or of complete or partial suppression of disease were primarily due to antibiotic effects from the associated soil fungi or bacteria, as affected by the various soil amendments. Essentially this view was advanced in an earlier paper (6).

SUMMARY

The differential effect of 18 soil supplements on the virulence and persistence of *R. Solani* in fertile, natural, black virgin soil, artificially infested, was observed during six to eight successive 21-day re-plantings in six experiments, involving approximately 14,000 potato seedlings.

In general, the various nitrogenous salts and cornmeal definitely tended to reduce disease, as well as the persistence of the pathogen, whereas sucrose, calcium hydrate, magnesium sulphate, and sulphur tended to be uniformly favourable. Sucrose was usually more favourable to both disease and the pathogen's persistence than any other supplement tested. The effect of dextrose was variable. Apparently conditions for maximum virulence and persistence of the pathogen were, in general, more uniformly favourable in natural soil than in those treated.

The reduction of disease and apparent decline of the pathogen in the soil are tentatively attributed to antibiotic effects from the associated soil fungi and bacteria, as modified by certain treatments, and not to any lack of available nutrients or to unfavourable soil temperature, water content, or pH.

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THE EFFECT OF WHEAT GERM OIL IN POULTRY RATIONS[1]

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[Received for publication June 19, 1947]

REVIEW OF LITERATURE

Vitamin E or α-tocopherol, of which wheat germ oil is a potent source, was shown by Card, Mitchell and Hamilton (27) to be essential for hatchability. The feeding of 0.5 ml. of wheat germ oil per day to hens receiving a diet treated with ether and ferric chloride to destroy vitamin E, brought about an immediate and marked increase in hatchability. Withdrawal of the oil resulted in a marked falling off in hatchability and reduction in egg laying. However, these authors pointed out that, from a practical feeding standpoint, there was little cause for concern with regard to possible vitamin E deficient rations, because all whole grains and many green feeds are good sources of the vitamin. Card (26) had shown that the addition of wheat germ oil to a practical ration did not improve either fertility or hatchability. Adamstone (1) investigating the hatchability of eggs laid by birds on a diet deficient in vitamin E, found that all the embryos died. During early development, the rate of growth and differentiation was slower than normal and some embryos died during the first two days as a result of disintegration of the circulatory system or its failure to become established. There was a critical period at the end of the fourth day beyond which few embryos survived, due to the formation of a lethal ring in the blastoderm. Juhasz-Schaffer (53) found that the addition of wheat germ oil to the embryonic tissues cultured in adult chickens' plasma resulted in a tremendous increase in the amount of growth. Mohler (60) reported that the vitamin E content of eggs was influenced by the vitamin E content of the feed. It was also found that vitamin E was a factor in hatchability. Barnum (17) found with hens on a normal diet, and a deficient diet supplemented with wheat germ, that the vitamin E content of the eggs was about equal but was much greater than that of eggs from hens on the deficient diets alone. The embryonic mortality during the first four days of incubation was 7 to 8 per cent with the normal and wheat germ diets and hatchability was 73 and 46 per cent, respectively. With the deficient diets the early embryonic mortality ranged from 17 to 29 per cent and the hatchability from 16 to 27 per cent. Unpublished data from our laboratory (22) showed that the hatchability of eggs laid by birds reared from hatching on a semi-purified diet consisting of polished rice 56, dried brewer's yeast 15, casein 20, salt mixture 4, and cod liver oil 5 parts was increased from 7.6 per cent to 49.8 per cent by the addition of 10 parts of wheat germ, replacing the same amount of polished rice. However, we were by no means satisfied that this increase was due to vitamin E alone, if at all. Ender (42) reported that the fertility and hatchability of eggs from hens fed on a diet containing abundance of vitamins A, D and the B complex, with only small amounts

[1] A contribution from the Departments of Animal Nutrition and Poultry Husbandry. This work was supported in part by a Fellowship established by the Ogilvie Flour Mills, Montreal, Quebec.

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of vitamin E, were increased from 80 and 43 per cent to 88 and 71 per cent, respectively by the administration of 0.17 to 0.18 gms. of wheat germ oil per hen daily. Dols (40, 41) fed comparable groups of White Leghorns and Rhode Island Reds on a normal ration with access to grass, with and without additional vitamin E in the form of a wheat germ concentrate. This concentrate did not affect either the fertility or hatchability of the eggs. However, Adamstone (6) presented histological evidence indicating the natural occurrence of vitamin E deficiency in chick embryos. Later, he (9) also reported that the spontaneous haemorrhage and associated histological picture occasionally seen in chick embryos is probably caused by a vitamin E deficiency. Davidson and Schaible (39) found that inclusion of 5 per cent wheat germ meal in a practical ration did not have any significant effect on fertility, hatchability, egg production or mortality. Holmes, Craven and Halpin (52) and Holmes and Craven (50) reported that the addition of cold pressed wheat germ oil at the rate of 0.5 ml. per bird per day to hens fed on a practical ration had no beneficial effect in so far as fertility, egg production and hatchability were concerned. There was no significant difference in the viability of chicks hatched from the controls and the wheat germ oil groups. Masson (59) fed a small group of hens a daily supplement of 2 mgs. of alpha tocopherol acetate in oil, for three months, without effect on the hens, the fertility of the eggs or their hatching. Actually the mortality in the control group was less than in the E-fed group.

Adamstone and Card (14, 15) found that male birds possessed a remarkable ability to withstand vitamin E deficiency, all of the males being capable of fertilizing eggs after one year on a deficient diet. Not all of the males were sterile after two years on the diet. Histological studies revealed degenerative changes in the testes. It appeared that the sperm was a carrier of a definite store of the vitamin. Titus and Burrows (80) investigated the influence of wheat germ oil on semen production of cockerels using a basal ration untreated and treated with ferric chloride in ether to destroy vitamin E. The ferric chloride treatment had little, if any, effect on semen production. The addition of 0.5 per cent of cold pressed wheat germ oil actually caused a marked decrease in semen production. Adamstone (10) reported that male fowls fed on a ration deficient in vitamin E did not respond as readily to injection of testosterone, as did control males receiving alpha tocopherol.

From these reports it can be concluded that, although vitamin E is required by poultry for fertility and hatchability, there is little evidence that the addition of wheat germ oil or extra wheat germ to ordinary rations is of benefit. In fact, the vast bulk of the evidence shows that their addition is without effect on fertility, egg production or hatchability.

Adamstone (2, 3, 4, 5) reported that chicks fed on a diet treated with ferric chloride to destroy vitamin E, developed a condition of imbalance and loss of muscular control with accompanying changes in the cerebellum. Degenerative lesions appeared in the visceral organs as well and histological studies showed a state of profuse cell proliferation following injury to the nuclei. In the later work, as a result of finding malignant growths (lymphoblastoma) of the liver, heart and other organs of chicks fed on the ferric

chloride treated diets, he suggested that vitamin E deficiency was at least partially responsible for the appearance of the growths. This work created interest in the possible relation between range paralysis (neurolymphomatosis), leukemia and vitamin E. Adamstone (12) later reported that chicks, fed on an iron treated vitamin E deficient diet, but receiving vitamins A and D in cod liver or sardine oil, developed ulcers in the intestine followed by tumours which were true malignant growths. These ulcers did not occur in chicks fed the same ration but receiving halibut liver oil. He (13) postulated that the action of vitamin E is related to the metabolism of anthracene compounds.

Butler and Warren (23, 24) and Butler, Warren and Hammersland (25) reported the successful treatment and prevention of fowl leukemia or leucosis, which included various leukemic and paralytic conditions, by the feeding of liberal amounts or injections of wheat germ oil. However, Sawyer, quoted by Norris (64) and Jungherr (57) failed to obtain any significant differences in symptoms, course and mortality rate of birds clinically affected with fowl paralysis between controls and those treated with wheat germ oil. Cole (28) obtained no beneficial effects in paralyzed birds by feeding or injecting wheat germ oil. Davidson and Schaible (39) reported that the addition of vitamin E, as 5 per cent wheat germ, equivalent to about 0.5 ml. of wheat germ oil per bird per day, to an ordinary ration had no preventive or curative effect on fowl paralysis, leucosis and related diseases. The leukotic mortality in the control birds was 25.5 per cent and in the treated birds 26.1 per cent. Jungherr (55, 56) found no beneficial effect on the course of the disease by injecting or feeding wheat germ oil. te Hennepe (49), Blakemore (21), Foggie (44) reported similar negative results. Barber (16) obtained some partial or temporary recoveries in paralyzed birds fed wheat germ oil, but the duration of the disease was not affected appreciably by the oil and the birds showed lymphomatous lesions on post mortem examinations. Taylor and De Ome (81) reported that the feeding of wheat germ oil had no appreciable effect on the incidence, type or age of onset of lymphomatosis. Biely and Cook (18) obtained no recovery in birds suffering from neurolymphomatosis by feeding or treating in various ways with wheat germ oil. Moreover, the incidence of fowl paralysis in birds reared on a ration containing 5 per cent wheat germ meal was not significantly different from that in birds fed on rations which were not supplemented. Johnson, quoted by Ewing (43) found wheat germ oil to have no curative value in leucosis. Titus, quoted by Norris (64) and Jungherr (57), in field trials involving some 3700 birds, in which 0.25 per cent wheat germ oil was incorporated in the ration, observed a fowl paralysis mortality of 30.8 per cent in the treated group and 31.8 per cent in the controls. Jungherr (57) reports 10 outbreaks of fowl paralysis in birds fed wheat germ oil fortified commercial rations from the time of hatching. Upp, quoted by Norris (64) and Jungherr (57), found 1 ml. of wheat germ oil per bird per day ineffective in the treatment of iritis.

Consideration of the above investigations can only lead to the conclusion that there is no direct relationship between vitamin E and neurolymphomatosis and that wheat germ or wheat germ oil does not possess any specific antileukotic effect.

Goettsch and Pappenheimer (45, 46), Pappenheimer and Goettsch (68, 69, 70, 71), Pappenheimer and Graff (73) and Pappenheimer, Goettsch and Jungherr (72) using a synthetic diet in studying the effects of vitamin E deficiency found that a lack caused a brain disorder, due primarily to impairment of capillary circulation and termed nutritional encephalomalocia or "crazy chick" disease. There are degenerative changes in the cerebellum and sometimes in the medulla and cerebrum. However, only a few chicks developed the disorder when fed on ordinary rations, even after treatment with ferric chloride in ether to destroy vitamin E. Protection was afforded by vegetable oils, or their non-saponifiable fraction, such as corn oil, cotton-seed oil, peanut oil and soyabean oil. Complete protection was achieved with alpha-tocopherol (natural vitamin E) or dl-alpha-tocopherol acetate (synthetic vitamin E). Confirmation of this protection has been reported by Dam, Glavind, Bernth and Hagens (36) and by Karrer, Fritzsche, Ringier and Solomon (58). Jungherr (54) observed nutritional encephalomalacia in the field.

The ration used by Pappenheimer and co-workers was high in fat, containing 21 per cent lard, and it is possible that the development of rancidity may be an important factor in the disease. Thus, the prevention of encephalomalacia may be due as well to the antioxidant activity of alpha tocopherol as to its vitamin effect. Norris (67) could prevent the development of the disorder on the high fat ration by feeding either natural or synthetic alpha tocopherol; alpha naphthol, an anti-oxidant, mixed with the lard ration markedly reduced the incidence and the same ration without lard did not result in encephalomalacia. Bauernfeind, Hodson and Norris, quoted by Norris (66), greatly decreased the development of encephalomalacia in chicks fed the Pappenheimer-Goettsch diet by feeding soybean oil independently of, but simultaneously with this diet. Ni (62, 63) prevented the disease equally well with soybean oil meal or with Chinese gelatin, which supports the hypothesis that the preventive effect of alpha tocopherol is not due to its vitamin characteristics.

Mohler (61) reported that in certain diets containing oils susceptible to rancidity, vitamin E was destroyed or rendered inactive. Hammond (47) demonstrated the presence of a factor in cod liver oil that hinders the utilization of vitamin E. However, it is possible that destruction of vitamin E was involved since Hammond and Harshaw (48) found that chicks fed on rations with excessive amounts of cod liver oil developed encephalomalacia. Wilgus and Thorp (82) state that disease is caused by the destruction of the nutritional factor by animal fats in the diet. Norris (65, 66) suggested that the occurrence of nutritional encephalomalacia in the field might be due either to a prolonged storage of feedstuffs or mixed feed at a temperature which accelerates fat deterioration or to the use of animal by-products containing highly rancid fats or to both these causes. Bauernfeind, Caskey and Norris, quoted by Norris (66) obtained results indicating that the storage of a mixed feed at room temperature for a period of two months promotes the development of nutritional encephalomalacia in the chicks to which the feed is given. Patrick and Morgan (76) found that chicks receiving inadequate vitamin E not only showed symptoms of encephalomalacia but also developed vitamin A deficiency. In a later report (77) they concluded that vitamin E was necessary for the

utilization of vitamin A and carotene from simplified rations containing lard and that field encephalomalacia was probably a vitamin A deficiency. Parker, Neish and McFarlane (74) studied the anti-oxidant activity of wheat germ oil for stabilizing vitamin A. Adamstone (7) stated that nutritional encephalomalacia can be produced regularly in chicks if the vitamin E in the diet is destroyed by treatment with ferric chloride in ether and the ether evaporated by heat. If the heat is not used, or the food is treated with ether without ferric chloride and the ether evaporated with heat, the disease does not occur. The addition of corn oil or peanut oil or wheat germ to the diet is largely effective in preventing the disease which seems to be caused by lack of vitamin E together with some other factor.

In spite of this wealth of experimental evidence it is difficult to draw any definite conclusion. There appears to be no doubt that there is a relationship between nutritional encephalomalacia and vitamin E. The bulk of the evidence would suggest that this relationship is not due to its vitamin activity *per se* but rather is an indirect one, associated with its antioxidant properties in preventing the onset of rancidity and subsequent destruction of other nutritional factors. Under certain conditions vitamin E itself appears to be inactivated or destroyed. However, there is little evidence that the disorder is of much practical importance.

Another disorder, exudative diathesis, may appear separately or concomitantly with encephalomalacia, in chicks fed on vitamin E deficient rations. Dam and Glavind (31, 32, 33, 34) report the symptoms as due to plasma exuding from the capillaries, as a result of increased permeability and there are massive accumulations of fluid in the subcutaneous tissue or general oedema of the muscles and connective tissue. Dam and Glavind (32, 33) and Dam, Glavind, Prange, and Ottesen (37) found that alpha tocopherol protected against the disorder. Bird and Culton (20) and Bird (19) confirmed the occurrence of generalized oedema, with considerable accumulation of fluid in the pericardium and peritoneal cavity. Alpha or beta tocopherol were active in preventing the condition but some antioxidants were ineffective.

However, exudative diathesis can be accelerated or suppressed by dietary changes which are unrelated to the vitamin E content of the diet. Dam and Glavind (35), Bird (19) and Dam (30) reported that increasing the soluble salts in the diets, particularly sodium chloride or other inorganic salts which tend to accumulate in the extracellular fluid, enhances the occurrence of the exudates. Both exudative diathesis and encephalomalacia are accelerated by fat, according to Dam, Glavind, Prange and Ottesen (37). Dam (29) attributed this to the highly unsaturated fatty acids present. In later work (30) he found that purified diets containing no added fat rarely produced exudates and never encephalomalacia. The fatty acids from cod liver oil, lard, linseed oil and commercial unsaturated C_{20} acids, at a level of about 5 per cent in the diet, favour the appearance of encephalomalacia. Oleic acid and rancid cod liver oil were ineffective in producing either symptom. A high lard intake favours encephalomalacia more than exudates. Inositol, at a 1.5 per cent level, counteracted both disorders. Two per cent lipocaic counteracted only exudative diathesis whereas 1 per cent cholesterol hastened the symptoms of diathesis when the diet contained 5 per cent cod liver oil and a low salt content but suppressed

encephalomalacia on a high lard diet. It was concluded that the effect of the different fatty acids consisted in damage of tissue rather than in general destruction of vitamin E and that inositol, lipocaic and cholesterol do not act simply through a general pro- or anti-oxidant effect. Dam and Kelman (38) found some decrease in plasma phospholipids in vitamin E deficient chicks. Adamstone (11) reported that the cholesterol content of the brain of vitamin E deficient chicks, with nutritional encephalomalacia, decreased markedly during the third week of life, while that of the controls increased.

Another symptom related to vitamin E deficiency was observed by Adamstone (8). Chicks on a diet deficient in vitamin E, supplemented with halibut liver oil, developed an anaemia from phagocytosis of the erthryocytes in the liver. There was an increase of myeloid elements in the bone marrow and deposition of an iron compound, probably hemosiderin, in the liver. The anaemia did not occur if sardine oil or cod liver oil was fed. He concluded that the anaemia was probably caused by deficiency of vitamin E or of an unknown substance essential to the red cells.

Holmes and Craven (51) reported that the addition of 0.1 per cent wheat germ oil to the ration did not significantly affect growth, mortality or age to sexual maturity in chicks. Patrick and Morgan (75) using a synthetic diet have shown that chicks require vitamin E, supplied as alpha tocopherol, for efficient use of feed for growth. They suggest that the requirement is less than 300 micrograms per 100 grams of ration.

Again, it seems evident, that, although chicks require vitamin E for normal growth and development, the addition of wheat germ oil to ordinary rations is without effect.

Probably as a result of this association of vitamin E with range paralysis, nutritional encephalomalacia and allied disorders and with rancidity and the stabilization of vitamin A and so forth in stored feeds, numerous inquiries were received from poultrymen and feed manufacturers concerning the effect of, or necessity for wheat germ oil in poultry rations in relation to growth, mortality, egg production, fertility and hatchability. Hence a study was initiated in 1939* on the effect of wheat germ oil in poultry rations. Two types of the wheat germ oil were used, a pressed oil and an extracted oil.

EXPERIMENTAL

1. Chick Starter Rations to Ten Weeks of Age

Six groups of newly hatched Barred Plymouth Rock chicks, each consisting of fifty cockerels and fifty pullets, sight sexed, were used in this phase of the investigation.

The basal ration had the following composition:

	Pounds		Pounds
Rolled wheat	15.5	Soybean oil meal	2.0
Wheat bran	3.0	Dried buttermilk	5.0
Wheat germ	5.0	Meat meal	4.0
White hominy	15.5	Fish meal	1.0
Ground yellow corn	17.0	Cod liver meal	0.5
Rolled barley	5.0	Dehydrated cereal grass	2.0
Rolled oat groats	15.0	Iodized salt	0.5
Ground oats	5.0	Cod liver oil	1.0
Ground peas	3.0		

* This study was continued in 1940 but due to the war and subsequent absence of the senior author on active service with the R.C.A.F., was not reported in detail. A summary report appeared in the 65th Annual Report of the Ontario Agricultural College.

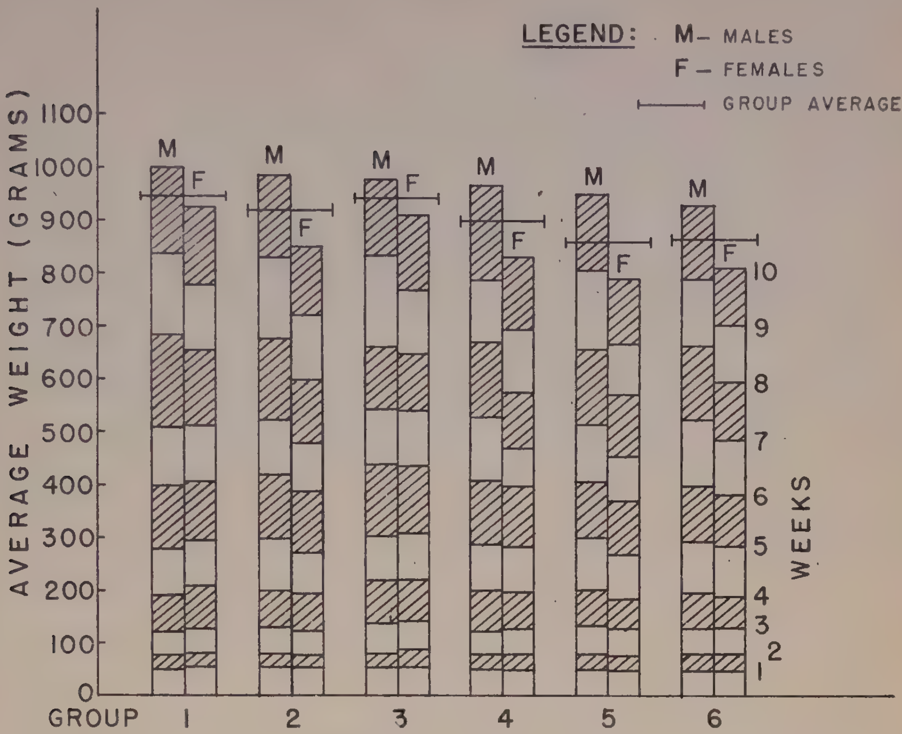

FIGURE 1. Average weekly weights and gains of the six groups of chicks from hatching to 10 weeks. Groups 1, 3, and 4 were fed a starting mash containing wheat germ and Groups 2, 5, and 6 on the mash without wheat germ. Groups 3 and 5 received extracted wheat germ oil and Groups 4 and 6 received pressed wheat germ oil.

Manganese sulphate was added to this ration at the rate of eight ounces per ton. The cod liver oil contained at least 1000 International units of vitamin A and 100 A.O.A.C. chick units of vitamin D per gram. Bone meal, oyster shell and insoluble grit were supplied *ad libitum*.

This basal ration will hereafter be referred to as Ration No. 1. Another ration, known as Ration No. 2, was this same ration with the wheat germ omitted and replaced by the same amount of rolled wheat.

The various groups of chicks were fed as follows:

Group 1—Ration No. 1
Group 2—Ration No. 2
Group 3—Ration No. 1 plus extracted wheat germ oil
Group 4—Ration No. 1 plus pressed wheat germ oil
Group 5—Ration No. 2 plus extracted wheat germ oil
Group 6—Ration No. 2 plus pressed wheat germ oil

Both wheat germ oils were incorporated into the rations in the amounts recommended by the producers.* The chicks were banded and individually weighed once a week during the experiment. Throughout the experiment the various groups were maintained in wire-floored battery brooders in an air conditioned room. Until four weeks of age starting batteries with electric hovers were used. At that time the birds were transferred to growing batteries, without hovers. Feed and water were before the birds at all times.

* The amount of wheat germ oil used in these rations is considered by the Ogilvie Flour Mills to be a trade secret. For this reason, the exact amounts incorporated are not shown.

TABLE 1.—AVERAGE WEEKLY WEIGHTS OF CHICKS, SURVIVAL AND FEED CONSUMPTION DATA

Group		Average weekly weights (grams) and survivors																				Group average 10 wks.	Mortality	Grams feed per gram gain
		1		2		3		4		5		6		7		8		9		10				
1	♂	53	42†	78	41	124	40	191	39	278	39	399	39	507	39	684	39	837	39	1002	39	946	3	2.83
	♀	56	58†	82	57	130	56	210	56	297	55	409	55	513	55	655	55	777	55	924	55		3	
2	♂	54	50†	80	50	130	50	202	50	297	48	421	48	524	48	676	47	831	47	986	47	920	3	2.92
	♀	53	50†	78	47	126	47	196	46	271	46	388	46	478	46	600	46	721	46	852	46		4	
3	♂	55	49†	83	49	137	49	219	49	304	49	438	49	546	49	663	48	834	48	977	48	944	1	3.01
	♀	56	51†	88	50	144	48	222	47	312	47	437	47	543	47	649	47	771	47	911	47		4	
4	♂	53	52†	81	51	125	50	201	50	287	50	411	50	528	50	673	50	788	50	968	50	900	2	3.03
	♀	51	48†	81	48	128	48	198	48	284	48	399	48	468	48	575	48	692	48	830	48		0	
5	♂	51	44†	80	44	134	44	203	43	301	43	407	43	515	43	656	43	805	43	949	43	858	1	3.20
	♀	49	56†	77	55	127	55	185	54	268	54	369	54	454	54	571	54	667	54	788	54		2	
6	♂	51	49†	79	49	129	49	196	48	294	48	401	48	525	48	664	48	787	48	929	47	866	2	2.93
	♀	50	51†	79	51	131	51	191	48	286	48	383	48	486	48	595	47	702	47	812	47		4	

† Number of birds surviving.

TABLE 2.—AVERAGE WEEKLY WEIGHTS OF BIRDS, SURVIVAL AND FEED CONSUMPTION DATA FROM 10 TO 24 WEEKS

Group		Average weekly weights (grams) survivors															Group average 24 weeks	Mortality	Feed consumption pounds		Feed gain ratio
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24			Mash	Grain	
1	♂	1043 25*	1130 25	1187 25	1496 23	1658 23	1802 23	2060 23	2081 22	2276 21	2422 20	2617 20	2737 20	2811 20	2892 20	2980 20	2445	5	950	916	8.98
	♀	924 55*	1016 55	1130 51	1236 51	1387 51	1494 51	1608 51	1712 51	1781 51	1923 51	1999 50	2055 50	2077 50	2113 50	2231 50		1			
2	♂	999 25*	1061 25	1173 23	1363 21	1616 21	1779 21	1979 21	2025 20	2274 15	2444 14	2622 14	2756 14	2760 14	2859 14	2979 14	2404	11	912	839	11.67
	♀	852 46*	930 46	1008 42	1139 41	1298 41	1387 41	1539 41	1655 41	1768 41	1889 41	1995 41	2055 41	2077 41	2116 41	2207 41		1			
3	♂	1008 25*	1175 25	1253 25	1449 25	1588 25	1774 25	2042 25	2157 22	2303 20	2384 20	2629 20	2831 20	2883 20	2946 20	3015 20	2495	5	1029	810	9.91
	♀	911 47*	1025 47	1108 43	1224 43	1361 43	1477 43	1588 43	1720 43	1846 43	1969 43	2066 43	2084 43	2128 42	2128 41	2242 41		2			
4	♂	987 25*	1071 25	1172 24	1412 24	1597 24	1731 24	1965 23	2109 23	2269 23	2508 22	2630 22	2885 22	2975 22	3023 22	3104 22	2572	3	1026	849	8.28
	♀	830 48*	916 48	988 43	1257 43	1303 43	1414 43	1528 43	1631 43	1769 43	1864 43	2018 43	2094 43	2105 43	2179 43	2277 43		1			
5	♂	982 25*	1042 25	1225 25	1339 25	1515 25	1641 25	1923 24	2068 23	2242 23	2397 23	2620 22	2727 22	2867 22	2939 22	3057 22	2439	3	951	930	8.13
	♀	788 54*	937 54	1010 50	1084 50	1217 49	1385 49	1512 49	1540 49	1670 49	1775 49	1913 49	1924 49	1955 49	2016 49	2141 49		1			
6	♂	920 25*	1107 25	1224 25	1341 24	1506 24	1618 24	1890 24	1994 24	2133 22	2238 21	2423 21	2580 21	2769 21	2800 21	2932 21	2580	4	935	885	8.14
	♀	812 47*	922 47	1019 42	1171 42	1318 42	1438 42	1614 42	1696 42	1831 42	1933 42	2047 42	2129 42	2194 42	2285 42	2404 42		1			

* Number of survivors.

Growth curves are shown in Figure 1 and the weekly weights, mortality and feed consumption data are given in Table 1. Some of the chicks were incorrectly sexed and as soon as the error was evident, the chicks were placed in their correct pen and the survivors are shown from the beginning of the experiment on the basis of the correct sex. The individual weights of each group at ten weeks of age were subjected to statistical examination.

Examination of the standard errors for the mean weights of the birds at ten weeks on the various diets showed that a difference of 35-38 grams between the mean weights was required for significance (odds 19 to 1).

It is obvious that the addition of either extracted or pressed wheat germ oil to either Ration No. 1 or No. 2 was without beneficial effect upon growth or food utilization. The statistical treatment did not show any differential response of sex to the diets. The finding that the addition of wheat germ oil to Ration No. 2, containing no added wheat germ was without beneficial effect, is especially significant. Mortality in all groups was considered normal for battery reared birds. In view of some unavoidable spillage of feed associated with battery rearing, it is probable that the differences between the various groups in economy of utilization of food for growth are negligible. In any case these differences do not favour the wheat germ oil fed groups.

It is concluded that the addition of either extracted or pressed wheat germ oil to an ordinary chick ration had no beneficial influence upon growth, mortality or economy of gain during the first ten weeks of life.

2. Growing Rations from Ten to Twenty-four Weeks of Age

In the practical rearing of poultry, the birds would be gradually changed at about ten weeks of age from starter rations to growing rations which generally have a lower protein content. However, such rations are designed primarily for use with birds on range and not reared in batteries. Although it was desired to carry out these tests on as practical a basis as possible, it was decided to continue these birds on the starter rations but to give them access to a "scratch grain" mixture.

The basal ration was unchanged from that previously used, and the various groups were fed as shown in the previous trial. The "scratch grain" was a mixture consisting chiefly of cracked yellow corn and whole wheat with some oats and barley and a little buckwheat. Bone meal, oyster shell and insoluble grit were fed *ad libitum*. The mash and grain, as well as water, were before the birds at all times.

The number of cockerels in each group from the first trial was reduced to 25 for this experiment by selecting the birds nearest to the average weight of the group at ten weeks of age. All pullets surviving in each group at the end of the first trial were continued on this experiment. The birds were maintained in wire screen floored growing batteries throughout the test. Due allowance of space was made as growth progressed. All birds were individually weighed, to the nearest gram each week.

The average weekly weights of each sex, the mortality and feed consumption data are shown in Table 2. Growth is presented graphically in Figure 2. At the end of the eleventh week four pullets, near the average

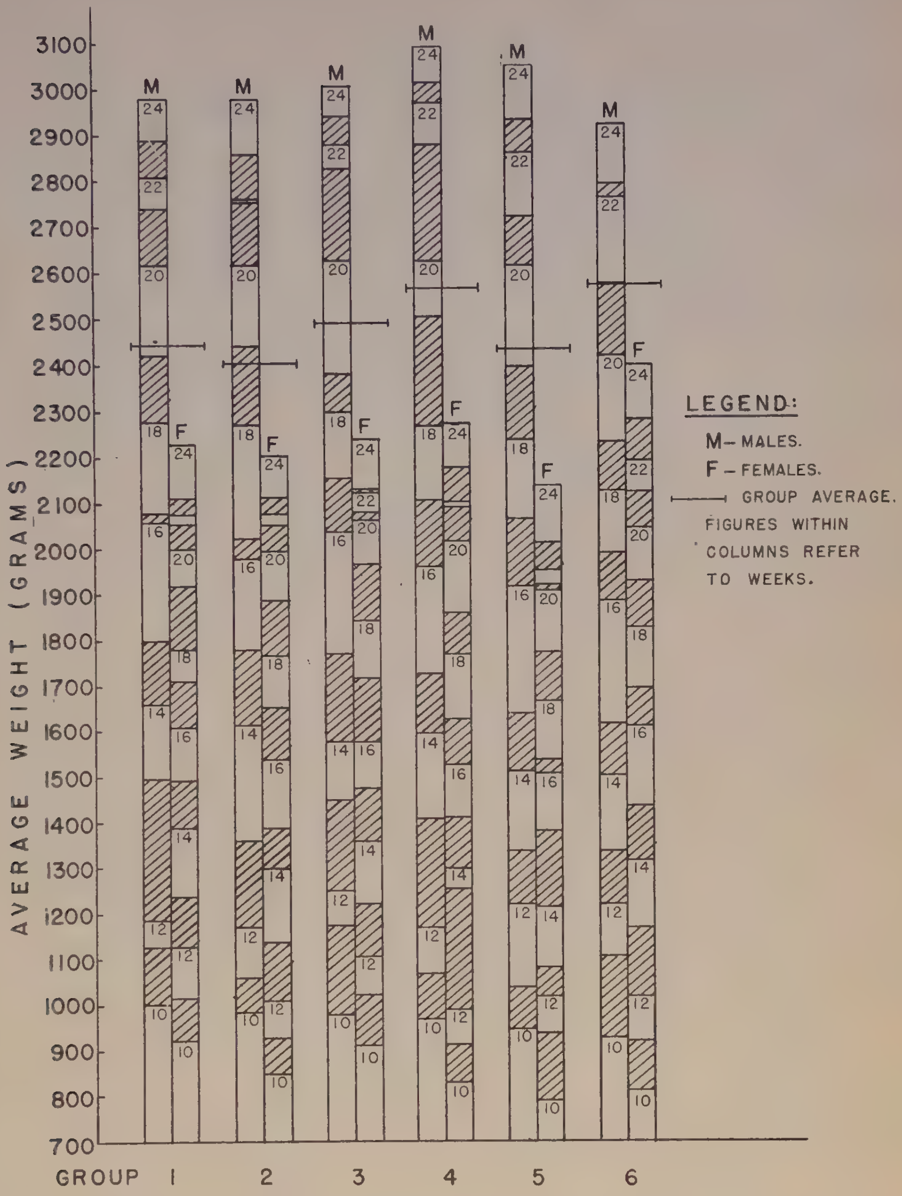

FIGURE 2. Average weekly weights and gains of the six groups of growing birds from 10 to 24 weeks. Groups 1, 3, and 4 were fed on a starting mash containing wheat germ together with a scratch grain mixture and Groups 2, 5, 6 on the mash without wheat germ together with a scratch grain mixture. Groups 2 and 5 received extracted wheat germ oil and Groups 4 and 6 received pressed wheat germ oil.

TABLE 3.—INFLUENCE OF RATIONS ON SEXUAL MATURITY OF PULLETS

Group	Date first egg	Total egg production		Number birds laying during December	Mortality (December)
		November	December		
1	Nov. 21	3	329	36	3
2	Nov. 30	2	321	40	7
3	Nov. 22	5	221	30	9
4	Nov. 18	20	364	36	3
5	Nov. 21	8	246	32	7
6	Nov. 19	7	422	40	3

weight of the group, were removed from each group and used for another experiment which will be considered later in this paper. These were not considered in the mortality data.

The growth data were subjected to statistical treatment. There was no significant difference in weight between any of the groups. The difference in growth response of the males and females was the same on the several diets within the limits of experimental error. The mortality was due, in so far as could be ascertained, entirely to cannibalism. It will be noted that the mortality of the cockerels was higher in every group than that of the pullets. This is probably to be expected in battery rearing. Whether the mortality in Group 2, which was considerably greater than that in any other group, was related to the fact that their ration did not contain any added wheat germ or wheat germ oil or was coincidence, must, due to the vagaries of cannibalism and battery rearing, remain an open question. Since the feed-gain ratio was calculated by dividing the total feed consumed during the period by the total weight at the end of the trial less the total weight at the beginning of the trial in each group, mortality is an important factor. Hence it is considered that differences in economy of utilization of feed are due to mortality rather than the diet. This is borne out by comparison of the feed-gain ratios of those groups with comparable mortality. The feeding of wheat germ oil had no effect on growth and development to six months of age.

There was no difference in time of development of sexual maturity as judged by the onset of egg laying in the various groups. The pertinent data are shown in Table 3. Since the pullets were not in individual batteries it was impossible to determine the exact number which were in production during November. It would seem apparent that the wheat germ oil had no effect on the development of sexual maturity.

At the end of the twenty-four week period, five cockerels from each group, considered to be representative of the group, were killed and the testes removed, weighed and examined histologically. There was a very great variation in the weight of the testes of individuals in each group. In fact, this variation was so great that the numbers were too small to warrant any conclusions. However, the range in testes' weight appeared to be about the same in all groups. This variation in size also complicated the histological studies but there was no evidence of any effect due to the wheat germ oil feeding.

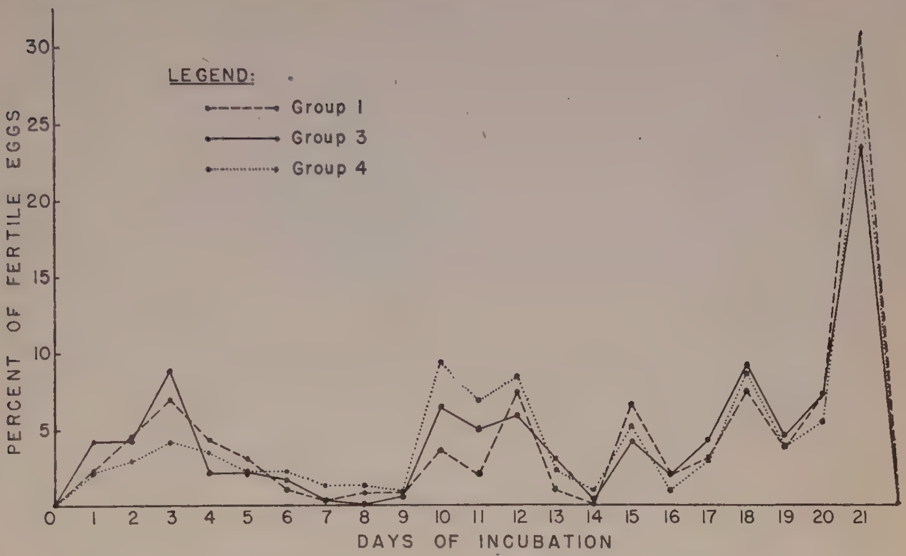

FIGURE 3. Distribution of embryonic mortality during incubation of eggs laid by groups of pullets fed on a hatching ration containing wheat germ. Group 3 received extracted wheat germ oil and Group 4 received pressed wheat germ oil.

3. Egg Production and Hatchability

At the end of the twenty-fourth week, five cockerels were selected from each group for breeding purposes and the remainder were discarded. These cockerels were selected by a member of the Poultry Department, who had no knowledge of their previous dietary regime, and in his opinion were representative of the group. Twenty pullets from each of the first five groups were placed in five large wire screen floored batteries. Twenty pullets from the sixth group were placed in an individual hen battery in the Poultry Building. No selection of these birds was made, the first 20 in each group according to leg bands being taken. The remainder of the pullets in each group were placed in individual hen batteries in an Animal Nutrition Building. Both buildings were heated and during the winter months electric lights were used to give a twelve hour day.

The groups in the Poultry Building were used for egg production, fertility and hatchability studies, while those in the Animal Nutrition Building were used for egg production studies only. During December, any birds dying in those groups housed in the Poultry Building to be used for hatchability studies were replaced by birds from the same group in the Animal Nutrition Building. No replacements were made after the end of December. At the same time, if the total number in each group of pullets in the Animal Nutrition Building dropped below 24, due to mortality or their use as replacements, birds of the same age, of similar breeding and reared in batteries and fed on the same basal ration, but from another experiment, were used as replacements. Again no replacements were made after the end of December. For about two weeks following the rearrangement and grouping of these birds, they were fed on the starter ration with grain. The mashes were then gradually changed from the starter to hatching or laying mashes as the case might be. A cockerel from the group of five which had been reared on the respective diets was placed in the battery, in rotation, daily.

The mashes used had the following composition:

Laying mash	Pounds	*Hatching mash*	Pounds
Ground yellow corn	20	Ground yellow corn	20
Yellow hominy	5	Yellow hominy	5
White hominy	10	White hominy	5
Rolled wheat	20¾	Rolled wheat	21½
Wheat germ	3¾	Wheat germ	5
Wheat middlings	3¾	Wheat middlings	2½
Wheat bran	2½	Wheat bran	2½
Rolled barley	5	Rolled barley	5
Crushed oats	15	Crushed oats	16¼
Oat middlings	2½	Oat middlings	2½
Soybean oil meal	2	Soybean oil meal	1
Dehydrated cereal grass	2	Powdered milk	10
Meat meal	4	Cod liver meal	½
Powdered milk	1¼	Dehydrated cereal grass	2
Fish meal	1½	Iodized salt	½
Iodized salt	½	Bone meal	¼
Fortified cod liver oil	½	Fortified cod liver oil	½

Four ounces of manganese sulphate were added to each ton of the laying mash and eight ounces to each ton of the hatching ration. The fortified cod liver oil contained at least 400 A.O.A.C. units per gram. Bone meal, oyster shell and insoluble grit were before the birds at all times. The birds were allowed to consume mash *ad libitum* but scratch grain was fed once a day in weighed amounts, to insure approximately equal consumption of mash and grain. The scratch grain was the same mixture as used in the growing trials, consisting chiefly of cracked yellow corn and whole wheat with some oats and barley and a little buckwheat. The laying and hatching mashes as shown will be referred to as Ration No. 1. As with the starting and growing rations, a second mash, known as No. 2, with the wheat germ omitted and replaced by the same amount of rolled wheat was used.

The various groups were fed as follows:

Group 1—Ration No. 1*
Group 2—Ration No. 2*
Group 3—Ration No. 1* plus extracted wheat germ oil
Group 4—Ration No. 1* plus pressed wheat germ oil
Group 5—Ration No. 2* plus extracted wheat germ oil
Group 6—Ration No. 2* plus pressed wheat germ oil

*Either laying mash or hatching mash.

Both wheat germ oils were incorporated in the laying and hatching mashes in the amounts recommended by the producers.

All eggs with intact shells from February 15 to April 30, inclusive, laid by Groups 1 to 5 on the hatching rations were incubated. The results are shown in Table 5. The distribution of embryonic mortality during the incubation period is shown in Figures 3 and 4. The per cent hatchability is based upon total fertile eggs set.

It will be seen that neither of the wheat germ oils had any beneficial effect on either fertility or hatchability. The distribution of embryonic mortality during incubation offers no evidence that the addition of the wheat germ oil had any effect.

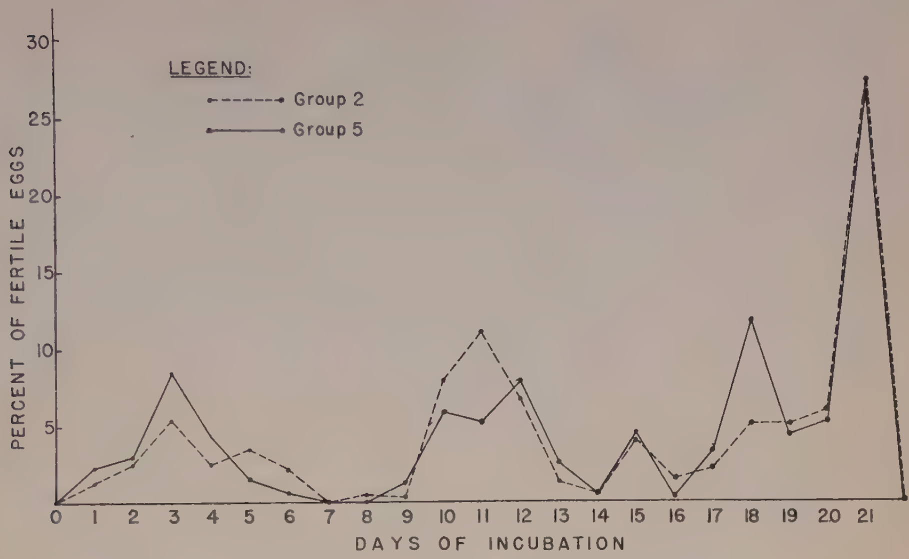

FIGURE 4. Distribution of embryonic mortality during incubation of eggs laid by groups of pullets fed on a hatching ration which did not contain wheat germ. Group 5 received extracted wheat germ oil.

Hatchability in all groups was exceedingly poor. The hatchability of eggs laid by birds of similar breeding and fed on the same basal rations but reared on range and housed in the conventional manner, was from 70 to 80 per cent of the fertile eggs set. We are of the opinion that the method of rearing, particularly the provision of range, is an important factor. A large part of the embryonic mortality in these studies with battery-reared pullets was the result of chondrodystrophy. Of the total embryonic mortality during the period, 20.4 per cent of the dead embryos in the fertile eggs laid by Group 1 had the abnormality, 17.9 per cent in the eggs of Group 2, 20.0 per cent in Group 3, 25.7 per cent in Group 4 and 15.7 per cent in Group 5. Smith and Branion (78, 79) concluded that chondrodystrophy and other embryonic abnormalities were either eliminated or greatly reduced by the provision of good grass range. Direct sunlight was another possible factor.

At the conclusion of these trials at the end of May, the birds were divided into 3 groups of 40 each, taking in so far as possible equal numbers from each of the 6 original groups. One group was maintained indoors in two of the batteries but whenever possible the windows were opened so that direct sunlight reached the birds. A second group was housed outdoors in a conventional type pen with access to a good grass range and the third group were similarly housed but their range was only in fair condition. Hatching studies were conducted on all eggs with intact shells laid during the second and the fourth week of June. The first group had a hatchability of 28.9 per cent of the fertile eggs set, the second group 55.5 per cent and the third group 48.1 per cent. With the last two groups the hatchability in the fourth week was appreciably higher than in the second week. There was only one case of chondrodystrophy in all of the embryos again confirm-

TABLE 4.—HATCHABILITY RESULTS

Group	Fertile eggs	Infertile eggs	Per cent infertility	Chicks hatched	Per cent hatch
1	636	40	5.9	284	44.7
2	520	14	2.6	201	38.6
3	528	30	5.7	170	32.2
4	413	27	6.5	99	23.7
5	400	47	11.2	98	24.5

TABLE 5.—EGG PRODUCTION STUDIES
(January 1-May 31)

Group	Feed consumption pounds†			Egg production			Pounds feed per dozen eggs	Mortality
	Mash	Grain	Total	Total	Hen days	Per cent		
1. Laying	453	374	827	1603	3364	47.7	6.2	3
Hatching	389	376	765	1466	2882	50.9	6.3	2
2. Laying	444	366	810	1446	3573	40.5	6.7	3
Hatching	340	357	697	1263	2900	43.3	6.6	3
3. Laying	411	363	774	1382	3520	39.3	6.7	3
Hatching	332	380	712	1186	2842	41.7	7.2	3
4. Laying	458	384	842	1476	3623	40.7	6.8	2
Hatching	346	366	712	1078	2873	37.5	7.9	2
5. Laying	459	382	841	1635	3469	46.8	6.2	3
Hatching	327	365	692	950	2926	32.4	8.8	1
6. Laying	504	341	845	1364	3544	38.5	7.4	2
Hatching	344	435	779	1465	2960	49.5	6.4	1

† This also includes the feed consumed by five cockerels in each group.

ing the value of sunshine and good range for hatchability. These results also suggest that the poor results previously obtained with these pullets were due to the rearing in confinement.

The egg production and feed consumption figures for both series, that is the corresponding groups on the hatching and laying mash, are shown in Table 5.

Again it will be seen that the addition of either pressed or extracted wheat germ oil to rations with or without wheat germ had no beneficial effect on egg production or on economy of feed utilization.

4. Oral Administration of Wheat Germ Oil

At the end of the first ten weeks, 40 representative cockerels were selected and divided into four groups of 10 each. During the eleventh week, 24 representative pullets were selected and divided into 4 groups of 6 each. Groups of 10 cockerels and 6 pullets were given orally each day, 0, 2, 4, and 6 drops, respectively of extracted wheat germ oil. All groups were fed on the starter ration with *ad libitum* grain. The birds were individually weighed weekly from the 12th to the 24th week.

The average weights of the cockerels at the end of the 24th week were 111, 111, 114, and 109 ounces, respectively in the control, 2, 4, and 6 drops groups. Corresponding weights for the pullets were 83, 82, 86 and 87 ounces respectively. One cockerel died in the "4 drops" group during the 23rd week and one died in the "6 drops" group during the 19th week. By the end of November, 1 pullet was laying in the control group, 2 in the "2 drops" group, 2 in the "4 drops" group and 1 in the "6 drops" group.

During the first two weeks of December, the birds were gradually changed over to a laying mash, fed with scratch grain to ensure about equal consumption of mash and grain. Bone meal, oyster shell and insoluble grit were fed *ad libitum*. The pullets were continued on this regime until the end of June. The average age to date of laying of the first egg was 185.8, 182.7, 180.8 and 178.2 days for the control, "2 drops," "4 drops," and "6 drops" groups, respectively. No birds died in the control group, 3 died in the "6 drops" group, 2 died in each of the other groups. The per cent egg production based upon hen days calculated for each individual from the onset of production to the end of the test or until the bird died was 37.8, 35.6, 25.9 and 25.0 per cent, respectively.

Admittedly these groups are small but again there is no evidence that oral administration of varying amounts of wheat germ oil had any beneficial influence on growth and development, age to sexual maturity or on egg production.

SUMMARY

The addition of either pressed or extracted wheat germ oil to ordinary rations with or without wheat germ, had no beneficial effect on the growth or mortality of young chicks to 10 weeks of age. Similarly there was no influence on growth and development to 24 weeks of age nor on sexual maturity as judged by the onset of egg production.

The inclusion of either pressed or extracted wheat germ oil in ordinary hatching or laying mashes, with or without wheat germ, was without effect on egg production, hatchability or fertility.

The oral administration of various amounts of extracted wheat germ oil to birds from the 10th to 24th week of age had no effect on growth and development nor on the onset of sexual maturity. Continued administration had no beneficial influence on egg production.

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UNIFORMITY OF WATER DISTRIBUTION BY SOME UNDERTREE ORCHARD SPRINKLERS[1]

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[Received for publication June 26, 1947]

One of the advantages claimed for sprinkler irrigation as compared with rill or furrow irrigation is that it wets the soil more uniformly. Tests conducted at this Station have shown this to be true, especially in sandy soils. It has only held true, however, where the sprinkler method has been used with reasonable intelligence. Cases have been encountered where orchard soils have been wetted in a very irregular manner by sprinkler irrigation.

Lack of uniformity of water distribution is the first major problem to be solved in connection with sprinkler irrigation. If the distribution is not uniform, the chief advantage of sprinkler irrigation is lost; that is, the soil is wetted in an irregular manner, and therefore the tree roots cannot make full use of the soil. Before any sprinklers are recommended for commercial use, therefore, their efficiency in distribution of water should be thoroughly tested.

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FIGURE 1. In order to measure the distribution of water by each sprinkler, No. $2\frac{1}{2}$ size tin cans were spaced in a 5×5 foot square pattern. The sprinkler was placed in the centre of this pattern and run for one hour; then the water in the cans was measured.

Undertree sprinkler irrigation has been practised in a number of British Columbia orchards for from 10 to 15 years. The sprinklers in common use have been mostly of the butterfly type. During the past two years, there has been a marked increase in interest in sprinkler irrigation, and an increasing number of growers have been installing undertree sprinkler systems. Newer types of sprinklers not used here before have come into common use. Because of this, it was considered desirable to test the uniformity of water distribution by these newer sprinklers and to compare them with the butterfly type. This paper presents the results of these tests.

Comparatively little investigational work appears to have been reported on the uniformity of spread of water by those sprinklers that are now in common use in the Pacific Northwest. In 1939, Powers and Bertramson (2) charted the uniformity of distribution from a Rainbird sprinkler used in pasture work. They also showed cross sections of the distribution patterns for several other sprinklers. In 1942, Christiansen (1) reported a highly comprehensive series of tests on a large number of sprinklers. He showed charts of water distribution for each sprinkler. He then assumed different spacings of the sprinklers, determined the amount of overlap, and calculated a "uniformity coefficient" for each spacing. By this means, he compared the efficiencies of different types of wetting patterns. He did not, however, name the sprinklers used. In 1944, Schoenleber (3) used a similar method for calculating the uniformity coefficient. However, he based his calculations on the wetted area from only one sprinkler at a time, and did not take into account overlapping from adjacent sprinklers.

PROCEDURE

Tin cans (size $2\frac{1}{2}$) were placed in a 5 × 5 foot square pattern on a level area of ground, and the sprinkler to be tested was placed in the centre of the pattern (Figure 1). The sprinkler was then run for one hour, and the water in each can was measured to the nearest cubic centimeter. The figures thus obtained were later converted into depths of water in inches.

The sprinklers tested were those that were in common use in 1946 for undertree sprinkling of British Columbia orchards. They included the Browning 50, with a $\frac{1}{8}$ inch nozzle (Figure 2); the Browning 6, with a 3/16 inch nozzle; the Browning 52, with two $\frac{1}{8}$ inch nozzles (Figure 3); the Rainbird 20LA, 7° angle, with 7/64, $\frac{1}{8}$, 5/32, and 3/16 inch nozzles (Figure 4); the Buckner 7M71, with two $\frac{1}{8}$ inch nozzles (Figure 5); and three different makes of butterfly sprinkler (Figure 6). The Browning 6 is simply a heavier edition of the Browning 50. With the Browning sprinklers, the water stream breaks against a small revolving wheel. The angle of the wheel can be adjusted in such a manner as to regulate the distance of throw and the rate of turning of the sprinkler head. In these tests, the sprinklers were adjusted to turn quite slowly. An attempt was also made to adjust them to throw the water as far as possible and still obtain reasonably uniform distribution. The Rainbird sprinklers turn slowly, with a hammer action. The Buckner 7M71 is a two-armed revolving sprinkler. It is adjustable for rate of turning and for distance of throw, by the simple

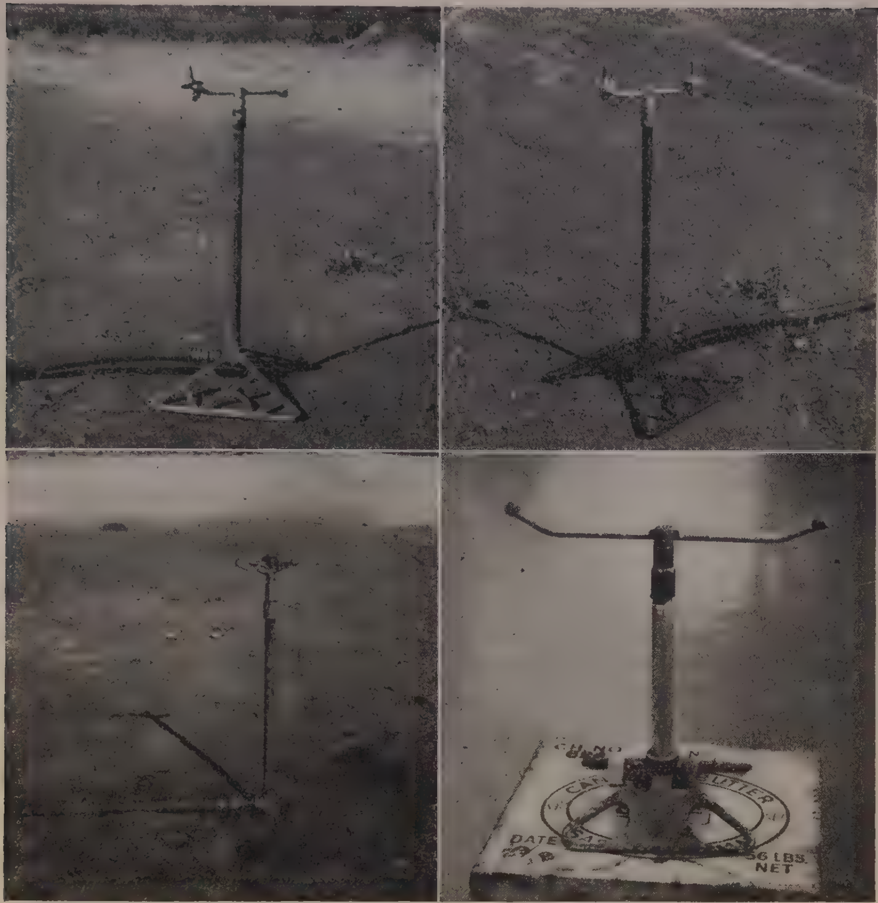

FIGURE 2. *(Upper left).* A Browning 50 sprinkler on a lawn sprinkler stand. The Browning 6 is similar but heavier. In this figure and in Figures 3 to 6, inclusive, the sprinkler heads were attached to whatever stands happened to be handy at the time the pictures were snapped.

FIGURE 3. *(Upper right).* A Browning 52 sprinkler.

FIGURE 4. *(Lower left).* A Rainbird 20LA sprinkler.

FIGURE 5. *(Lower right).* A Buckner 7M71 sprinkler.

expedient of bending the arms to suit. In these tests, they were adjusted to a slow rate of turning, and were flattened slightly at the tips in order to lower their trajectory. With the butterfly sprinklers, the water stream is deflected and scattered by a rapidly revolving spoon. A number of other types of sprinkler head were also tested, but as they did not prove suitable for undertree use they will not be mentioned in this report.

In almost every test, the sprinklers were run at successive pressures of 10, 15, 20, 30, 45 and 60 pounds per square inch, these pressures being measured and adjusted at the base of the sprinkler. The heads were placed at a height of 16 to 24 inches above the ground. All of the tests reported here were made when there was little or no wind.

TABLE 1.—UNIFORMITY AND OVERLAPPING COEFFICIENTS

Nozzle size	Pounds pressure	Diameter of circle	Uniformity coefficients at the following sprinkler spacings								Overlapping coefficients		
			20×20	25×25	30×30	40×40	20×30	20×40	20×50	20×60	20×20	20×40	40×40
Rainbird 20LA, 7° nozzle													
7/64	15	43	53	58	40	—	45	—	—	—	3.6	—	—
	20	48	67	63	57	24	54	40	—	—	4.5	2.2	1.1
	30	54	82	73	67	31	74	62	40	—	5.7	2.8	1.4
	45	58	88	83	86	66	84	78	59	47	7.0	3.5	1.7
	60	64	85	86	82	72	71	78	60	39	7.6	3.8	1.9
1/8	10	39	48	36	25	—	44	—	—	—	2.7	—	—
	15	45	66	61	58	29	48	45	—	—	4.1	2.0	1.0
	20	52	75	67	73	46	69	62	42	—	5.3	2.6	1.2
	30	59	78	80	77	64	78	68	57	36	6.7	3.3	1.6
	45	66	83	84	79	78	86	81	72	52	8.6	4.3	2.1
	60	74	86	82	79	70	90	81	82	68	9.5	4.7	2.3
5/32	10	32	62	17	10	—	38	—	—	—	2.1	—	—
	15	41	63	69	50	26	58	45	—	—	3.8	1.9	0.9
	20	44	78	70	67	45	63	58	35	—	5.0	2.5	1.2
	30	52	84	89	76	60	86	74	58	—	7.1	3.5	1.7
	45	60	88	89	81	75	84	82	68	47	7.6	3.8	1.9
	60	66	88	92	86	72	87	84	79	57	8.8	4.4	2.2
3/16	10	34	66	42	26	—	61	—	—	—	2.0	—	—
	15	40	78	69	66	46	77	64	—	—	3.6	1.8	0.9
	20	46	85	71	73	59	70	74	47	—	4.5	2.1	1.1
	30	54	87	85	75	69	80	75	68	39	6.4	3.2	1.6
	45	64	87	87	83	80	89	77	82	65	9.1	4.6	2.3
	60	70	88	91	83	79	87	82	80	69	8.4	4.3	2.1
Browning 50													
1/8	10	24	46	11	—	—	5	—	—	—	1.5	—	—
	15	32	67	41	52	—	54	—	—	—	2.0	—	—
	20	37	74	73	67	—	73	40	—	—	3.0	1.5	—
	30	44	87	84	76	51	86	55	—	—	4.2	2.1	1.0
	45	56	89	88	79	73	91	83	56	—	7.0	3.3	1.6
	60	61	93	90	83	80	75	90	72	48	8.6	4.3	2.1
Browning 6													
3/16	10	31	66	59	35	—	37	—	—	—	2.0	—	—
	15	36	72	66	62	—	72	39	—	—	3.2	1.6	—
	20	44	79	79	69	35	84	66	—	—	3.9	1.9	0.9
	30	50	85	82	57	48	82	86	—	—	4.9	2.4	1.2
	45	58	92	83	78	73	82	86	64	40	7.2	3.6	1.8
	60	65	95	82	82	70	89	77	52	31	6.8	3.4	1.7
Browning 52													
1/8 + 1/8	10	—	40	—	—	—	—	—	—	—	1.0	—	—
	15	—	68	67	—	—	51	—	—	—	2.0	—	—
	20	—	79	69	63	—	73	42	—	—	3.2	1.6	—
	30	—	81	79	78	43	87	60	33	—	4.9	2.4	1.2
Buckner 7M71													
1/8 + 1/8	10	30	57	37	15	—	29	—	—	—	2.0	—	—
	15	36	62	49	58	—	60	28	—	—	3.0	1.5	—
	20	44	86	72	71	—	78	47	—	—	3.5	1.7	—
	30	47	84	81	68	45	78	60	33	—	4.4	2.2	1.1
	45	46	91	89	82	45	88	57	34	—	4.6	2.3	1.1
	60	45	88	93	70	37	83	51	26	—	4.6	2.3	1.1

TABLE 1.—UNIFORMITY AND OVERLAPPING COEFFICIENTS—*Continued*

Nozzle size	Pounds pressure	Diameter of circle	Uniformity coefficients at the following sprinkler spacings:								Overlapping coefficients		
			20 × 20	25 × 25	30 × 30	40 × 40	20 × 30	20 × 40	20 × 50	20 × 60	20 × 20	20 × 40	40 × 40
Butterfly 1													
	15	36	64	55	37	—	54	24	—	—	2.9	1.4	—
	20	39	69	66	43	—	59	33	—	—	3.2	1.6	—
	30	45	66	56	32	−12	51	26	3	—	4.0	2.0	1.0
	45	46	79	65	42	− 6	59	33	8	—	4.4	2.2	1.1
	60	44	77	56	25	−25	49	20	−3	—	4.0	2.0	1.0
Butterfly 2													
	15	—	75	75	56	—	85	45	—	—	3.8	1.9	—
	20	—	81	74	71	—	75	55	—	—	4.5	2.2	—
	30	—	79	73	57	14	67	42	18	—	5.1	2.5	1.2
	45	—	75	70	66	− 3	64	34	11	—	4.2	2.4	1.2
	60	—	66	60	9	−23	54	26	0	—	3.8	1.6	0.9

When the sprinkler tests were completed, a map was made of the results of each hour's run, showing the amount of water received by each can within the area of wetting (Figure 7). Each of these maps depicted the distribution of water from a sprinkler at one position only, and thus did not take into account any possible overlapping from adjoining sprinklers, such as would be encountered under actual orchard operations. In order to assess the uniformity of distribution properly, it was considered necessary to take into account the overlapping of wetted areas at different sprinkler spacings. Accordingly, calculations were made of the water distribution and of its uniformity at sprinkler spacings of 20 × 20, 25 × 25, 30 × 30, 40 × 40, 20 × 30, 20 × 40, 20 × 50, and 20 × 60 feet. In doing this, it was assumed that if four sprinklers had been placed at the four corners of the area under consideration (*e.g.* 20 × 20 feet), they would each have distributed their water in exactly the same manner as did the one sprinkler used. The procedure used in making the calculations was as follows:

1. Make map of area wetted, showing water distribution in a 5 × 5 foot pattern (as already explained). Divide pattern into four quarters in accordance with the points of the compass, as shown in Figure 7.

2. Make a diagram of the proposed spacing, divided into 5-foot squares. A 30 × 30 foot spacing is illustrated in Figure 8.

3. Assume that the sprinkler is to be placed at each corner of the space in turn, and copy into the squares those figures that lie in the proper direction from the sprinkler. This has been done in Figure 8, using the data from Figure 7. First, the figures in the SE corner of Figure 7 were inserted into the proper squares in Figure 8, starting with the figure nearest the sprinkler (.185) in the upper left corner. Then the figures in the SW corner of Figure 7 were inserted, starting with .257 in the upper right corner of Figure 8. The same was then done with the NE and NW quarters of Figure 7, starting at the lower left and lower right corners respectively of Figure 8. Thus by placing the sprinkler at each of the four corners of Figure 8 in turn, the data in Figure 7 were all inserted into the proper squares.

It frequently happened that the sprinkler threw the water farther than the width of the space selected. In such a case, further overlapping of the wetted areas occurred. This is illustrated in Figure 9, in which a 20 × 20 foot spacing is charted. The data from Figure 7 have been transferred into the proper squares in Figure 9, in the same manner as in Figure 8. The procedure is somewhat complicated, however, by the double overlapping of the sprinklers. It is necessary to visualize a sprinkler spaced every 20 feet in both directions in Figure 7. Thus in the SE corner of Figure 7, the first four figures in the top line (.185, .077, .057, .098) are entered in the chart in Figure 9 as usual. The fifth figure, however (.051), is beyond the next sprinkler spacing, and so is placed with .185 in the upper left-hand square. In the same way, the top four lines in this quarter are placed in their respective order in Figure 9, but the fifth line (.057, .015) is beyond the next sprinkler and so is placed in the top squares again in the chart. This assures that no matter where the sprinkler is placed, the water falling immediately to the SE of it is entered in the upper left square of the chart. The other three quarters are treated similarly.

FIGURE 6. A butterfly type of sprinkler.

4. Calculate the degree of overlapping of the wetted areas. This is done by the following equation:

$$V = \frac{T}{S}$$

in which V = the overlapping coefficient, T = the total number of entries in the chart, and S = the number of squares. Thus in Figure 8 the overlapping coefficient calculates out to 2.3, and in Figure 9 to 5.3. This means that on the average, the ground was wetted 2.3 times at each can in Figure 8, and 5.3 times in Figure 9. An overlapping coefficient of 1.0 indicates that on the average, each spot has been wetted from only one sprinkler. In such a case, it is more than likely that some spots would be wetted more than once and some not at all.

5. Calculate the uniformity coefficient. This is done in a manner similar to that used by Christiansen (1), except that the squares of the deviations from the mean are used, rather than the deviations themselves. The equation is as follows:

$$U = 100 - \frac{100\ S\ D}{M}$$

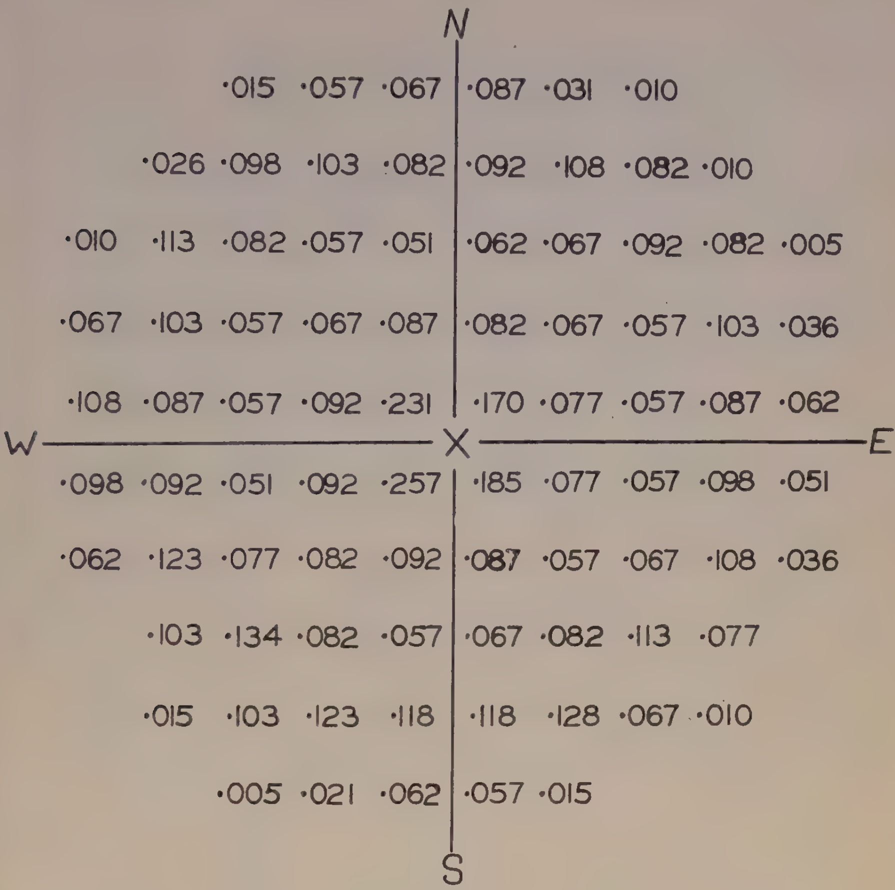

FIGURE 7. Distribution of water from a Rainbird 20LA (7°) sprinkler with a $\frac{1}{8}$ inch nozzle, at 20 pounds pressure. The cans were placed in a 5 $\times$ 5 foot pattern. The figures shown are in inches depth of water. N, S, W, E = the four points of the compass. X = position of sprinkler.

in which U = uniformity coefficient, SD = the standard deviation (4) of the total depths of water, copied from the squares in the charts, and M = the mean of these depths. This equation lays special stress on the extreme values. The coefficients of uniformity obtained in this manner are not as high as those obtained when deviations from the mean are used as a basis (1, 3). A value of 100 represents perfect uniformity, and a value lower than this proportionately less uniformity. By this method of calculation, very low values can and do come below zero.

Before the uniformity coefficients and overlapping coefficients were calculated, an examination was made of the charts. In some cases, it could be seen that the coefficients would be very low, and in most such cases they were not calculated.

RESULTS

Those results that are of special interest are presented in Table 1 and in Figures 10 to 15.

X X

·185 ·185	·077 ·098 ·175	·057 ·092 ·149	·098 ·051 ·149	·051 ·092 ·143	·257 ·257
·087 ·087 ·174	·057 ·062 ·031 ·150	·067 ·123 ·010 ·200	·108 ·077 ·015 ·200	·036 ·082 ·057 ·175	·092 ·067 ·159
·067 ·092 ·159	·082 ·108 ·190	·113 ·103 ·082 ·026 ·324	·077 ·134 ·010 ·098 ·319	·082 ·103 ·185	·057 ·082 ·139
·118 ·062 ·180	·128 ·067 ·010 ·205	·067 ·015 ·092 ·113 ·287	·010 ·103 ·082 ·082 ·277	·123 ·005 ·057 ·185	·118 ·051 ·169
·057 ·082 ·139	·015 ·067 ·067 ·149	·057 ·103 ·160	·005 ·103 ·057 ·165	·021 ·036 ·067 ·124	·062 ·087 ·149
·170 ·170	·077 ·108 ·185	·057 ·087 ·144	·087 ·057 ·144	·062 ·092 ·154	·231 ·231

X X

FIGURE 8. Chart showing method of calculating the water distribution, with overlapping from adjoining sprinklers taken into account. The data from Figure 7 have been copied into this chart, which represents a 30 × 30 foot square. The total for each 5 × 5 foot square is shown in larger type at the bottom of the square. The quarters in Figure 7 have been filled in here in the order SE, SW, NE, NW. X = position of sprinkler at each of the four corners. Overlapping coefficient = 2.3, and uniformity coefficient = 73.

Distribution Curves

The uniformity of distribution of water depends in part on the depth of application at successive distances from the sprinkler. Typical curves showing the depths obtained with each of several sprinklers are presented in Figures 10 to 15. The data used as a basis for these curves were obtained from those cans lying along or adjacent to the NW, NE, SW and SE points of the compass. The possibility of overlapping of wetted areas from adjacent sprinklers was ignored in making the necessary calculations. It will be noted that the depth-of-water scales are smaller in Figures 13 to 15 than in Figures 10 to 12.

Various types of curves are illustrated. With the Rainbird (Figures 10 and 11), there was more water applied close to the sprinkler than farther out. At the lower pressures, there was a second maximum farther out,

·185 ·092 ·051 ·026 ·057 ·092 **·503**	·077 ·108 ·015 ·098 ·051 ·005 **·354**	·057 ·082 ·103 ·092 ·021 **·355**	·098 ·010 ·257 ·082 ·098 ·062 **·607**
·087 ·062 ·036 ·005 ·123 ·113 **·426**	·057 ·067 ·077 ·082 **·283**	·067 ·092 ·082 ·057 **·298**	·108 ·082 ·092 ·051 ·062 ·010 **·405**
·067 ·082 ·036 ·103 ·103 **·391**	·082 ·067 ·134 ·057 **·340**	·113 ·057 ·082 ·067 **·319**	·077 ·103 ·057 ·087 ·067 **·391**
·118 ·170 ·015 ·062 ·087 ·087 **·539**	·128 ·077 ·103 ·031 ·057 ·015 **·411**	·067 ·057 ·123 ·010 ·092 ·057 **·406**	·010 ·087 ·118 ·231 ·108 ·067 **·621**

FIGURE 9. A further calculation of the water distribution in Figure 7, using a 20 × 20 foot spacing of the sprinkler. The data from Figure 7 have been copied into the 5 × 5 foot squares, as explained in the text. The total depth of water at each position is shown in larger type at the bottom of each square. X = four positions of sprinkler. Overlapping coefficient = 5.3, and uniformity coefficient = 75.

resulting in poor over-all distribution of water; but at higher pressures the distribution was much more uniform. The major effect of increasing the pressure was not so much to increase the average depth of application at any one point as it was to increase the area wetted. Comparing Figures 10 and 11, it can be seen that the larger nozzle (Figure 11) did not wet a larger area, but it did apply more water to the area wetted, and it applied it somewhat more uniformly. The Browning (Figures 12 and 13) likewise gave poorer distribution at low pressures than at high pressures. At low pressures, it threw most of its water in a narrow band. The same effects of increase in pressure and increase in nozzle size can be noted as with the Rainbird. With the Buckner and butterfly (Figures 14 and 15), an increase in pressure increased the rate of application near the sprinkler more than it did farther out. When the pressure was raised above 20 pounds, the increase in area wetted was negligible.

With all sprinklers, there was a tendency for the water to be thrown higher in the air as the pressure was increased. On the whole, the trajectory was lowest with the Browning and highest with the butterfly sprinklers.

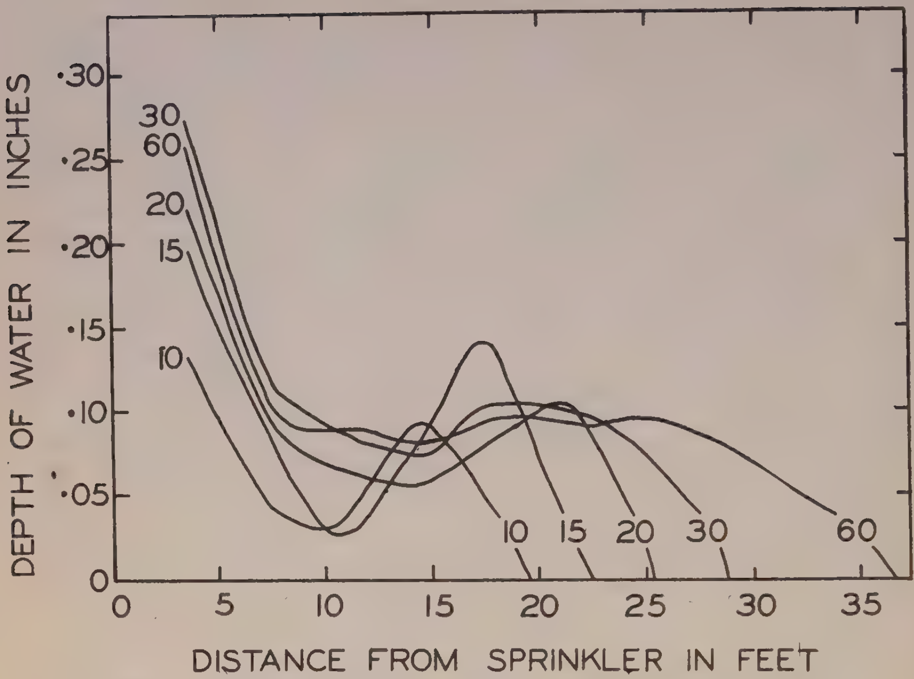

FIGURE 10. Water distribution curves from a Rainbird 20LA (7°) sprinkler with a $\frac{1}{8}$ inch nozzle, operating at pressures of from 10 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure.

With an increase in pressure, also, the drops became smaller. For both of these reasons, the spray was more easily blown aside by the wind at the higher pressures. An increase in nozzle size did not cause any increase in the trajectory; in fact, it appeared to lower it slightly.

Overlapping Coefficients

In order to illustrate the effect of an increase in sprinkler spacing on the amount of overlapping, the overlapping coefficients for 20 × 20, 20 × 40, and 40 × 40 foot spacings are shown in the last three columns of Table 1. As would be expected, there was a marked reduction in overlapping as the area allotted to each sprinkler was enlarged. With the Rainbird and Browning sprinklers, there was a steady increase in overlapping as the pressure was increased. This effect was much more marked with the closer spacings than with the wider spacings. With the Buckner and butterfly sprinklers, overlapping was increased little if any at pressures higher than 30 pounds. An increase in nozzle size had no consistent effect on the overlapping coefficient. This was possibly due to the fact that different sprinkler heads were used with each change in nozzle size.

Uniformity Coefficients

The uniformity coefficient has proved to be more reliable than the overlapping coefficient as a measure of the uniformity of water distribution. The uniformity coefficients for all spacings are shown in Table 1. The omission of a figure from this table indicates that the distribution of water at that spacing was very poor.

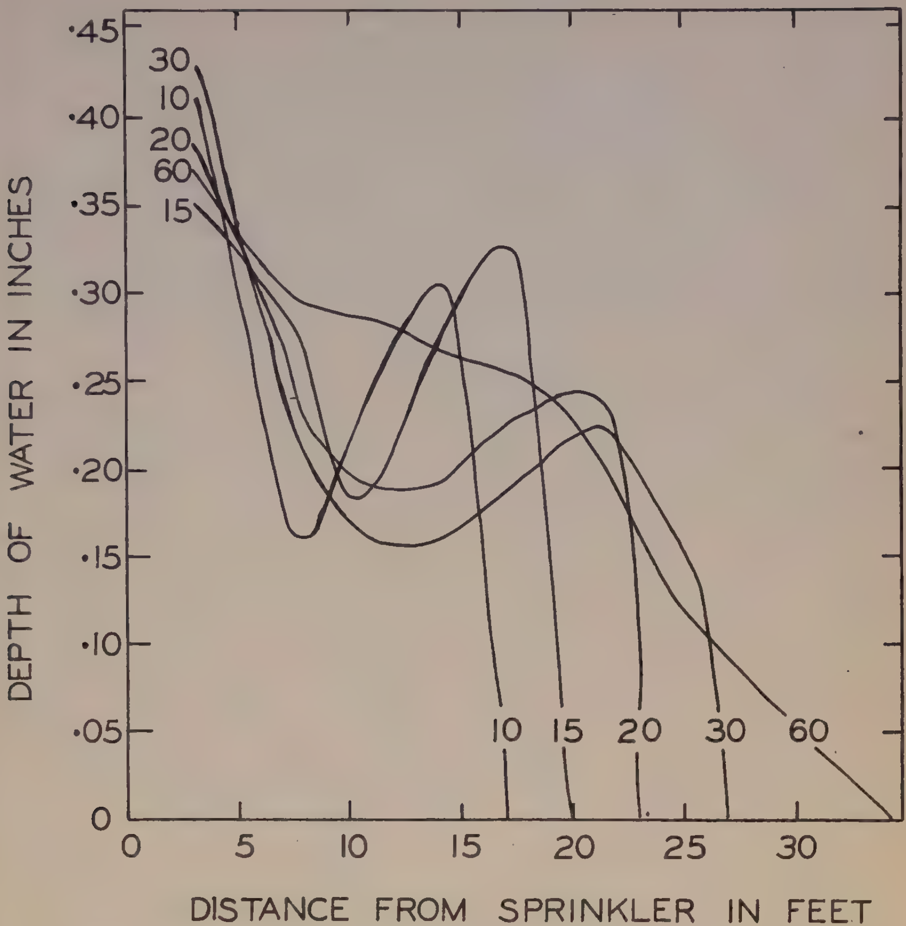

FIGURE 11. Water distribution curves from a Rainbird 20LA (7°) sprinkler with a 3/16 inch nozzle, operating at pressures of from 10 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure.

The effects of each factor on the uniformity coefficient were somewhat similar to the effects of this factor on the overlapping coefficient. In almost every case, the uniformity coefficients increased as the pressure was increased. This effect was especially marked with the smaller nozzles and with the wider spacings. Some irregularities in the results can be noted in Table 1. These are due to causes unknown—possible a slight breeze or nozzle irregularities.

The effects of variation in size of nozzle were not entirely consistent. With the Rainbird, an increase in nozzle size had little if any effect on the uniformity coefficient at the smaller spacings (*e.g.* 20 × 20, 25 × 25), but was accompanied by an increase in the uniformity coefficient at the wider spacings (*e.g.* 40 × 40, 20 × 50). The Browning gave higher coefficients with the 3/16 inch nozzle than with the $\frac{1}{8}$ inch nozzle at the lower pressures, but not always at the higher pressures.

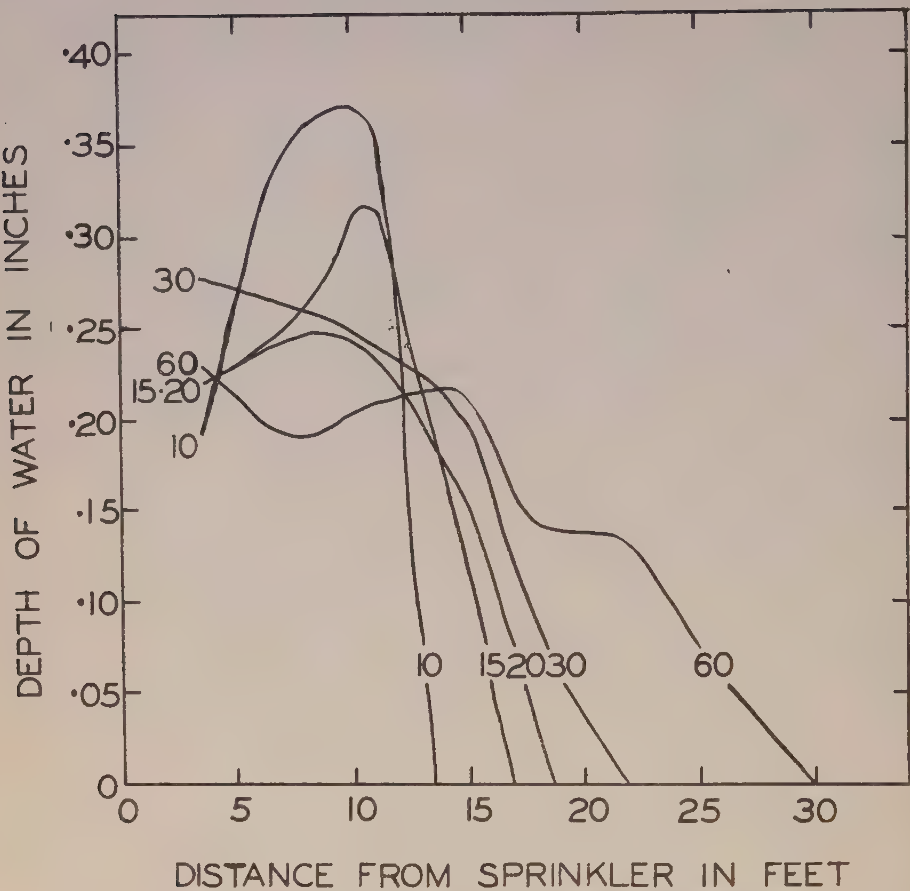

FIGURE 12. Water distribution curves from a Browning 50 sprinkler with a $\frac{1}{8}$ inch nozzle, operating at pressures of from 10 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure.

When the spacing was equidistant in both directions, an increase in distance of spacing was accompanied by a general decrease in the uniformity coefficient in almost every case. Exceptions to this were usually minor in nature. The effect was much more marked at the lower pressures than at the higher pressures. The uniformity coefficient also decreased when the spacing along one side was maintained at 20 feet and that along the other side was increased from 20 to 60 feet.

The data in Table 1 can be used to compare square spacing with rectangular spacing. Two such comparisons can be made with the same or approximately the same areas. There is little to choose between the 25 × 25 and the 20 × 30 foot spacings, in so far as the uniformity coefficients are concerned. The 30 × 30 foot spacing, however, shows better distribution of water than does the 20 × 45 foot spacing (obtained by averaging the 20 × 40 and the 20 × 50). If the uniformity coefficients had been calculated for the 20 × 80 foot spacing, they would have been so low that comparison with the 40 × 40 foot spacing would have been absurd. It thus appears that unless the two sides of the rectangle are not

greatly different in length, rectangular spacing cannot be counted on to give as good distribution of water as will square spacing. This is especially true at pressures of 30 pounds or less.

Comparing square spacing with rectangular spacing when unequal areas are involved is quite a different matter. For example, in an orchard where the trees are planted 30 × 30 feet apart on the square, the question may arise as to which would be preferable, spacing the sprinklers 30 × 30 feet or 20 × 30 feet (*i.e.*, with the sprinklers spaced 20 feet apart along the portable laterals and the laterals being moved 30 feet each time). Assuming no interference with water distribution by the trees, somewhat greater uniformity of distribution might be obtained with the 20 × 30 foot spacing, especially if the pressure were low.

The question arises as to just what degree of uniformity of water distribution should be aimed at. Perfection is impossible, even under ideal conditions; and too high a uniformity coefficient may be impractical or cost too much. An examination of the water distribution charts leads to the suggestion that a uniformity coefficient of at least 70 is desirable.

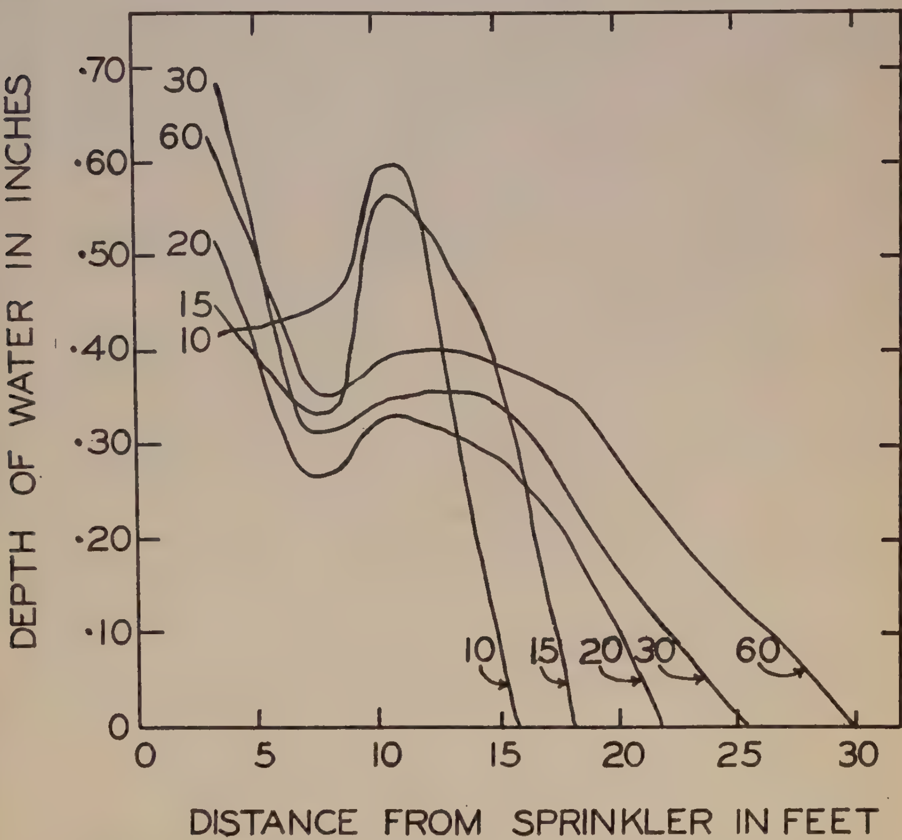

FIGURE 13. Water distribution curves from a Browning 6 sprinkler with a 3/16 inch nozzle, operating at pressures of from 10 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure. Note that the depth-of-water scale is shorter than in Figures 10 to 12.

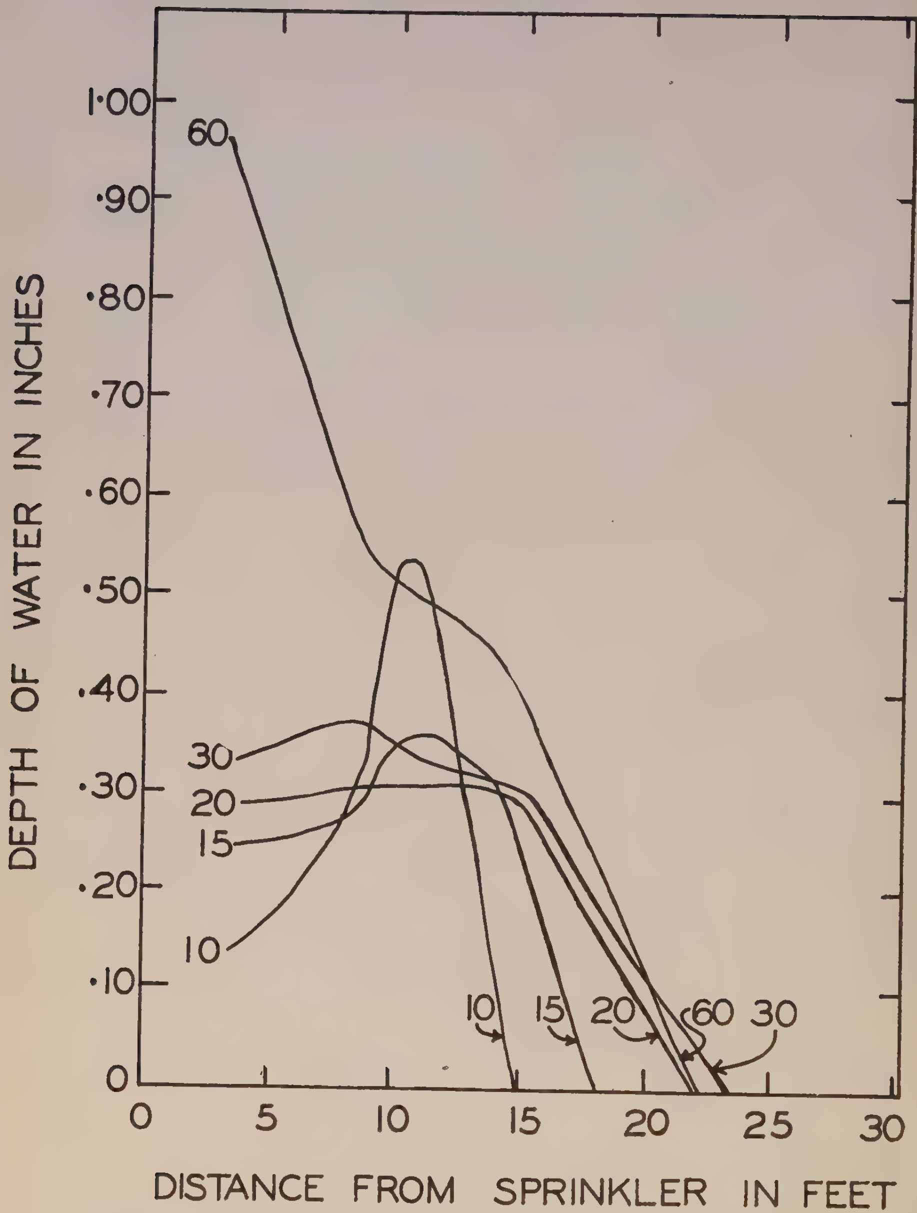

FIGURE 14. Water distribution curves from a Buckner 7M71 sprinkler, operating at pressures of from 10 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure.

Examples of two distributions are given in Figures 16 and 17, with coefficients of 64 and 72, respectively. It will be seen from these charts that even with coefficients of this size there is still considerable lack of uniformity; so that when 70 is suggested as a minimum, it can be assumed that a figure even higher than this would be preferable.

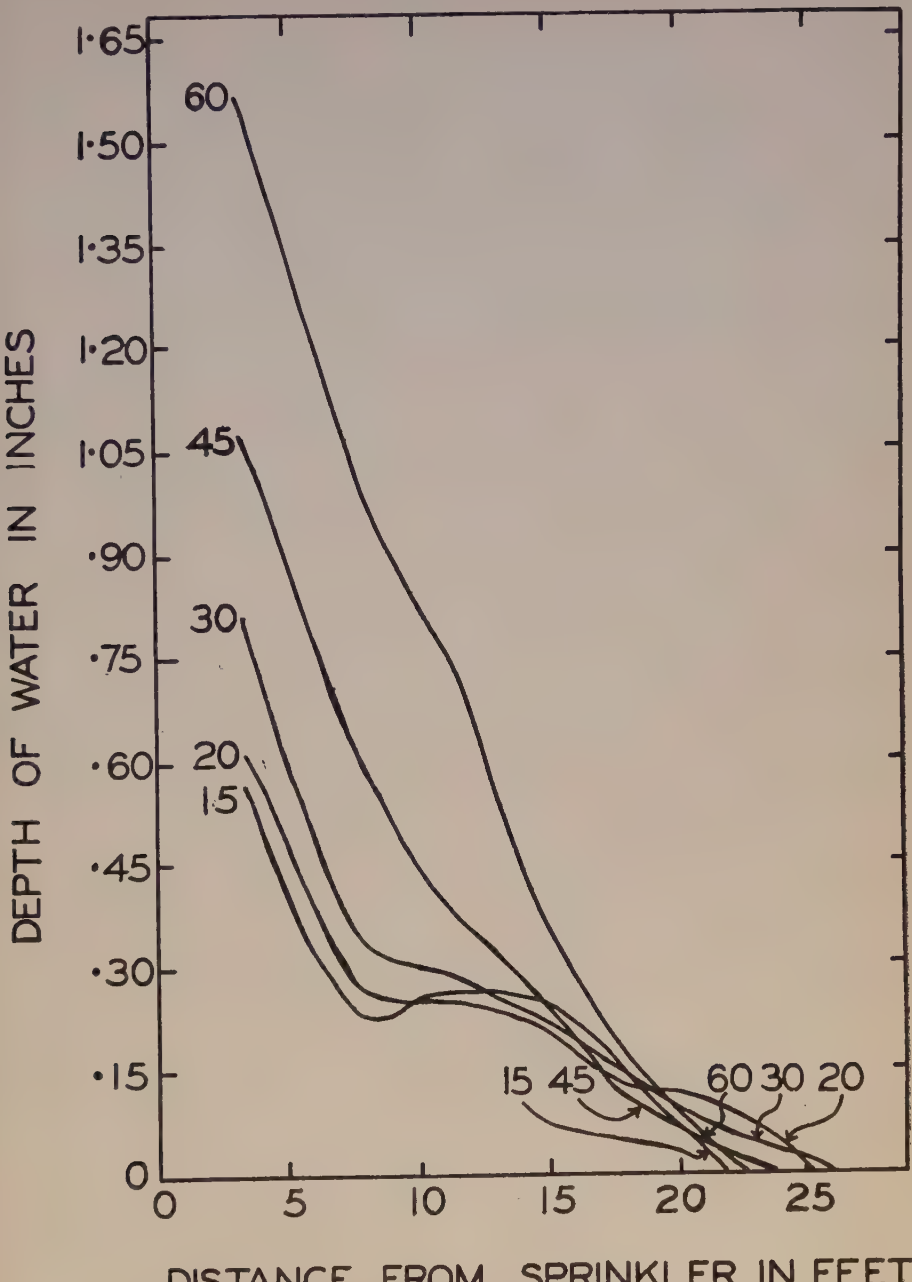

FIGURE 15. Water distribution curves from a typical butterfly sprinkler, operating at pressures of from 15 to 60 pounds per square inch. The figure attached to each curve represents the pounds pressure. Note that the depth-of-water scale is shorter than in Figures 10 to 14.

RECOMMENDATIONS

1. Pressures higher than 30 pounds per square inch are usually not necessary under orchard conditions, and in certain cases may even be undesirable. At higher pressures, the trajectory is higher and more of the spray hits the trees. At higher pressures, also, the drops of water are smaller and are more easily blown aside by the wind. And at higher pressures there is greater wear on the sprinklers. On the other hand, at pressures below 20 pounds the water is usually not distributed uniformly enough. On the whole, then, pressures of 20 to 30 pounds per square inch appear to be the most suitable for undertree use.

2. As a general rule, a square spacing is to be preferred to a rectangular spacing. However, as long as the rectangle is not too far from square in shape, it should prove reasonably satisfactory.

Under orchard conditions, there is the added factor of tree interference with the distribution of water. Where the trees are planted close together and are low and bushy, this interference may be quite serious. It is usually at a minimum when the sprinklers are placed in the centres of the tree squares. Since trees are usually planted on the square, square spacing of the sprinklers appears to show better promise for good distribution of the water in most orchards than does rectangular spacing.

3. Whatever sprinkler spacing is used, a combination of sprinkler, nozzle size and pressure should be used that will produce a uniformity coefficient of at least 70. Based on the results of this investigation, suggestions for such combinations are presented in Table 2. The pressures shown are the minimum pressures required to produce uniformity coefficients of approximately 70 under the conditions specified. Other than for the possibility that pressures above 30 pounds may (for reasons stated above) not always be suitable, pressures higher than those noted in this table should prove more satisfactory than lower pressures.

X X

1·02	·69	·64	1·00
·74	·69	·63	·74
·68	·68	·64	·65
·51	·58	·57	·52
·28	·32	·31	·27
·24	·22	·22	·22
·42	·51	·52	·42
.69	.75	.69	.65
·80	·80	.75	.74
·96	·74	·66	·92

X X

FIGURE 16. Water distribution from a Browning 6 sprinkler with a 3/16 inch nozzle, operating at 45 pounds pressure. The spacing is 20 × 50 feet. Each figure represents the depth of water in inches. The uniformity coefficient = 64. X = four positions of sprinkler.

TABLE 2.—MINIMUM PRESSURE SUGGESTIONS FOR DIFFERENT SPRINKLER SPACINGS

Spacing	Type of sprinkler		
	Rainbird 20LA	Browning 50 Browning 6	Browning 52 Buckner 7M71
20 × 20	7/64 – 25 lb. 1/8 – 20 lb. 5/32 – 20 lb. 3/16 – 15 lb.	1/8 – 20 lb. 3/16 – 15 lb.	1/8 + 1/8 – 20 lb.
25 × 25	7/64 – 30 lb. 1/8 – 25 lb. 5/32 – 20 lb. 3/16 – 20 lb.	1/8 – 25 lb. 3/16 – 20 lb.	1/8 + 1/8 – 20 lb.
30 × 30	7/64 – NR* 1/8 – 30 lb. 5/32 – 25 lb. 3/16 – 20 lb.	1/8 – 30 lb. 3/16 – 25 lb.	1/8 + 1/8 – 25 lb.
40 × 40	7/64 – NR 1/8 – NR 5/32 – NR 3/16 – 30 lb.	1/8 – NR 3/16 – NR	1/8 + 1/8 – NR
20 × 30	7/64 – 30 lb. 1/8 – 25 lb. 5/32 – 25 lb. 3/16 – 20 lb.	1/8 – 25 lb. 3/16 – 20 lb.	1/8 + 1/8 – 20 lb.
20 × 40	7/64 – NR 1/8 – 30 lb. 5/32 – 30 lb. 3/16 – 25 lb.	1/8 – NR 3/16 – 30 lb.	1/8 + 1/8 – 30 lb.
20 × 50	7/64 – NR 1/8 – NR 5/32 – NR 3/16 – 30 lb.	1/8 – NR 3/16 – NR	1/8 + 1/8 – NR
20 × 60	7/64 – NR 1/8 – NR 5/32 – NR 3/16 – NR	1/8 – NR 3/16 – NR	1/8 + 1/8 – NR

* NR—Not recommended.

It will be noted in Table 2 that the suggestions made do not accord entirely with the data in Table 1. This is because of the erratic nature of some of the results in Table 1. Under field conditions, even more erratic results can be anticipated. For this reason, recommendations have been based largely on the general trends in Table 1 rather than on the individual figures.

The nozzle and pressure suggestions made in Table 2 include those for 20 × 40, 40 × 40 and 20 × 50 foot spacings. These can be counted on to work satisfactorily only where there is little if any wind and where there is little if any interference with water distribution by the trees. Even with the other spacings included, the combinations noted cannot be counted on to give satisfactory water distribution in windy weather.

X X

·29	·46	·65	·40	·29
·38	·45	·58	·39	·41
·67	·58	·46	·63	·70
·44	·45	·60	·44	·45
·29	·44	·65	·38	·27

X X

FIGURE 17. Water distribution from a Buckner 7M71 sprinkler, operating at 20 pounds pressure. The spacing is 25 × 25 feet. Each figure represents the depth of water in inches. The uniformity coefficient = 72. X = four positions of sprinkler.

4. Of the sprinklers tested, only those listed in Table 2 appear suitable for undertree sprinkling. A number of others besides those listed in Table 1 were tested, but for one reason or another did not prove satisfactory. The butterfly sprinklers gave good water distribution at close spacings only, and they threw the water too high into the air. It should be noted that it may be possible to adjust the Browning and Buckner sprinklers in such a manner as to obtain somewhat wider distribution of the water than was obtained in these tests.

Although only three makes of sprinkler are listed in Table 2, it is not meant to imply that these are the only makes of sprinkler suitable for undertree use in orchards. There may indeed be a number of other sprinklers suitable for this purpose that were not tested.

SUMMARY

Sprinklers on sale in British Columbia for undertree use in orchards were tested for uniformity of water distribution. Each sprinkler was run for one hour, at pressures of 10, 15, 20, 30, 45 and 60 pounds per square inch. The water was caught in tin cans laid out in a 5 × 5 foot pattern, and was

then measured. Calculations of overlapping and of uniformity of water distribution were made for sprinkler spacings of 20 × 20, 25 × 25, 30 × 30, 40 × 40, 20 × 30, 20 × 40, 20 × 50, and 20 × 60 feet.

Various types of water distribution curves were obtained. At pressures of 15 pounds and lower, distribution was irregular with all sprinklers tested. Increasing the pressure from 10 to 60 pounds increased the area wetted with the Rainbird 20LA, Browning 50 and Browning 6; but with the Buckner 7M71 and butterfly sprinklers, the area wetted increased with pressure up to a pressure of 30 pounds only. At higher pressures, the spray was in all cases thrown higher in the air. For general use, pressures of 20 to 30 pounds appeared satisfactory.

The degree of overlapping of the wetted areas was affected in the same manner as was the size of the area wetted by any one sprinkler. There was little effect of nozzle size on the degree of overlapping.

The uniformity of water distribution at the various sprinkler spacings increased with pressure up to 60 pounds with the Rainbird and Browning, but up to 30 pounds only with the Buckner and butterfly. The effects of nozzle size on uniformity of distribution were not very consistent. As the area allotted to each sprinkler was increased, the degree of uniformity decreased. Water distribution was better with square spacing of the sprinklers than with rectangular spacing, when areas of the same size were compared.

Of the sprinklers tested, only the Rainbird 20LA, Browning 50, 6, and 52, and Buckner 7M71 were considered to be suitable for undertree use. Suggestions are offered for suitable minimum pressures for each nozzle size at each sprinkler spacing.

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